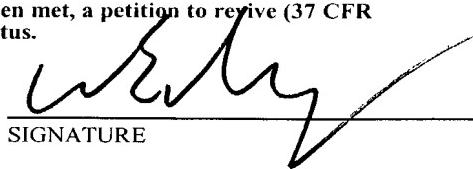
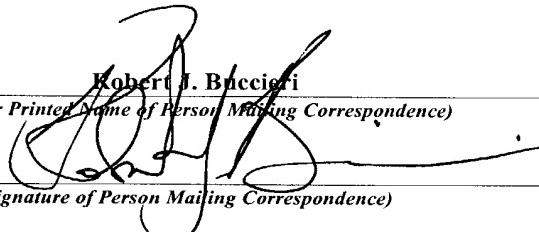


FORM PTO-1390 (Modified) (REV 11-2000)		U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER <b>112740-533</b>
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371				U.S. APPLICATION NO (IF KNOWN, SEE 37 CFR <b>10/070603</b>
INTERNATIONAL APPLICATION NO <b>PCT/DE00/03066</b>	INTERNATIONAL FILING DATE <b>September 5, 2000</b>	PRIORITY DATE CLAIMED <b>September 8, 1999</b>		
TITLE OF INVENTION <b>SYSTEM AND METHOD FOR OPTICAL INFORMATION TRANSMISSION (AS AMENDED)</b>				
APPLICANT(S) FOR DO/EO/US <b>Noe, Reinholt</b>				
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:				
<ol style="list-style-type: none"> <li><input checked="" type="checkbox"/> This is a <b>FIRST</b> submission of items concerning a filing under 35 U.S.C. 371.</li> <li><input type="checkbox"/> This is a <b>SECOND</b> or <b>SUBSEQUENT</b> submission of items concerning a filing under 35 U.S.C. 371.</li> <li><input checked="" type="checkbox"/> This is an express request to begin national examination procedures (35 U.S.C. 371(f)) The submission must include items (5), (6), (9) and (24) indicated below.</li> <li><input checked="" type="checkbox"/> The US has been elected by the expiration of 19 months from the priority date (Article 31).</li> <li><input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2))             <ol style="list-style-type: none"> <li>a. <input checked="" type="checkbox"/> is attached hereto (required only if not communicated by the International Bureau)</li> <li>b. <input type="checkbox"/> has been communicated by the International Bureau.</li> <li>c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US).</li> </ol> </li> <li><input checked="" type="checkbox"/> An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).             <ol style="list-style-type: none"> <li>a. <input checked="" type="checkbox"/> is attached hereto.</li> <li>b. <input type="checkbox"/> has been previously submitted under 35 U.S.C. 154(d)(4).</li> </ol> </li> <li><input checked="" type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))             <ol style="list-style-type: none"> <li>a. <input type="checkbox"/> are attached hereto (required only if not communicated by the International Bureau)</li> <li>b. <input type="checkbox"/> have been communicated by the International Bureau.</li> <li>c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.</li> <li>d. <input checked="" type="checkbox"/> have not been made and will not be made.</li> </ol> </li> <li><input type="checkbox"/> An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).</li> <li><input checked="" type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).</li> <li><input type="checkbox"/> An English language translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).</li> <li><input checked="" type="checkbox"/> A copy of the International Preliminary Examination Report (PCT/IPEA/409)</li> <li><input checked="" type="checkbox"/> A copy of the International Search Report (PCT/ISA/210).</li> </ol>				
<b>Items 13 to 20 below concern document(s) or information included:</b>				
<ol style="list-style-type: none"> <li><input type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98.</li> <li><input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.</li> <li><input checked="" type="checkbox"/> A <b>FIRST</b> preliminary amendment.</li> <li><input type="checkbox"/> A <b>SECOND</b> or <b>SUBSEQUENT</b> preliminary amendment</li> <li><input type="checkbox"/> A substitute specification.</li> <li><input type="checkbox"/> A change of power of attorney and/or address letter.</li> <li><input type="checkbox"/> A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.</li> <li><input type="checkbox"/> A second copy of the published international application under 35 U.S.C. 154(d)(4)</li> <li><input type="checkbox"/> A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).</li> <li><input checked="" type="checkbox"/> Certificate of Mailing by Express Mail</li> <li><input checked="" type="checkbox"/> Other items or information:</li> </ol>				
<b>Return Receipt Requested.</b>				

U.S. APPLICATION NO (IF KNOWN SEE 37 CFR <b>10/070603</b>	INTERNATIONAL APPLICATION NO <b>PCT/DE00/03066</b>	10/10 REFILED/PTO 08 MAR 2002 ATTORNEY'S DOCKET NUMBER <b>112740-533</b>		
24. The following fees are submitted:		<b>CALCULATIONS PTO USE ONLY</b>		
<b>BASIC NATIONAL FEE ( 37 CFR 1.492 (a) (1) - (5)) :</b>				
<input type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO ..... <b>\$1040.00</b> <input checked="" type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... <b>\$890.00</b> <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... <b>\$740.00</b> <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) ..... <b>\$710.00</b> <input type="checkbox"/> International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) ..... <b>\$100.00</b>				
<b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b>		<b>\$890.00</b>		
Surcharge of <b>\$130.00</b> for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492 (e)).		<input type="checkbox"/> 20 <input type="checkbox"/> 30 <b>\$0.00</b>		
<b>CLAIMS</b>		<b>NUMBER FILED</b>	<b>NUMBER EXTRA</b>	<b>RATE</b>
Total claims		31 - 20 =	11	x \$18.00
Independent claims		2 - 3 =	0	x \$84.00
Multiple Dependent Claims (check if applicable).		<input type="checkbox"/> <b>\$0.00</b>		
<b>TOTAL OF ABOVE CALCULATIONS</b>		<b>\$1,088.00</b>		
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27). The fees indicated above are reduced by 1/2.		<b>\$0.00</b>		
<b>SUBTOTAL</b>		<b>\$1,088.00</b>		
Processing fee of <b>\$130.00</b> for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492 (f)).		<input type="checkbox"/> 20 <input type="checkbox"/> 30	+ <b>\$0.00</b>	
<b>TOTAL NATIONAL FEE</b>		<b>\$1,088.00</b>		
Fee for recording the enclosed assignment (37 CFR 1.21(h)) The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable).		<input type="checkbox"/>	<b>\$0.00</b>	
<b>TOTAL FEES ENCLOSED</b>		<b>\$1,088.00</b>		
		<b>Amount to be: refunded</b>	\$	
		<b>charged</b>	\$	
<p>a. <input checked="" type="checkbox"/> A check in the amount of <b>\$1,088.00</b> to cover the above fees is enclosed.</p> <p>b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees A duplicate copy of this sheet is enclosed.</p> <p>c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <b>02-1818</b> A duplicate copy of this sheet is enclosed.</p> <p>d. <input type="checkbox"/> Fees are to be charged to a credit card. <b>WARNING: Information on this form may become public. Credit card information should not be included on this form.</b> Provide credit card information and authorization on PTO-2038</p>				
<p><b>NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.</b></p>				
<p>SEND ALL CORRESPONDENCE TO:</p> <div style="border: 1px solid black; padding: 5px; width: 100%;"> <p>William E. Vaughan Bell, Boyd &amp; Lloyd LLC P.O. Box 1135 Chicago, IL 60690-1135 Tel: 312-827-4292 Fax: 312-372-2098</p> </div>				
 <b>SIGNATURE</b>				
<p><b>William E. Vaughan</b></p> <hr/> <p>NAME</p> <hr/> <p><b>39,056</b></p> <hr/> <p>REGISTRATION NUMBER</p> <hr/> <p><b>March 8, 2002</b></p> <hr/> <p>DATE</p>				

<b>CERTIFICATE OF MAILING BY "EXPRESS MAIL" (37 CFR 1.10)</b>		1070603 Docket No. 112740-533	
Applicant(s): Noe, Reinhold			
Serial No. PCT/DE00/03066	Filing Date March 8, 2002	Examiner	Group Art Unit
Invention: <b>SYSTEM AND METHOD FOR OPTICAL INFORMATION TRANSMISSION (AS AMENDED)</b>			
<p>I hereby certify that the following correspondence:</p> <p><b>PCT- Transmittal Letter (duplicate); Preliminary Amendment (68 pgs.); Figures 1-14 (11 shts.); Copy of Int'l Application as filed (55 pgs.); English Language Translation of Int'l App. as filed (76 pgs.); Unexecuted Declaration &amp; POA (4 pgs.); Int'l Preliminary Exam. Report (6 pgs.); Int'l Search Report (4 pgs.); Check for \$1,088; Return Receipt Postcard.</b></p> <p style="text-align: center;"><i>(Identify type of correspondence)</i></p> <p>is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 in an envelope addressed to: The Assistant Commissioner for Patents, Washington, D.C. 20231 on</p> <p style="text-align: center;"><b>March 8, 2002</b></p> <p style="text-align: center;"><i>(Date)</i></p> <p style="text-align: center;">  <b>Robert J. Buccieri</b>  <i>(Typed or Printed Name of Person Mailing Correspondence)</i></p> <p style="text-align: center;"><i>(Signature of Person Mailing Correspondence)</i></p> <p style="text-align: center;"><b>EL891706605US</b></p> <p style="text-align: center;"><i>("Express Mail" Mailing Label Number)</i></p>			
<p><b>Note: Each paper must have its own certificate of mailing.</b></p>			

20070603 10/070603  
JC19 Rec'd PCT/PTO 08 MAR 2003

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IN THE UNITED STATES ELECTED/DESIGNATED OFFICE  
OF THE UNITED STATES PATENT AND TRADEMARK OFFICE  
UNDER THE PATENT COOPERATION TREATY-CHAPTER II

5

**PRELIMINARY AMENDMENT**

APPLICANT: Reinhold Noe DOCKET NO.: 112740-533  
SERIAL NO: GROUP ART UNIT:  
FILED: EXAMINER:  
INTERNATIONAL APPLICATION NO.: PCT/DE00/03066  
INTERNATIONAL FILING DATE 05 September 2000  
INVENTION: SYSTEM AND METHOD FOR OPTICAL INFORMATION  
TRANSMISSION

Assistant Commissioner for Patents,

Washington, D.C. 20231

Sir:

Please amend the above-identified International Application before entry  
10 into the National stage before the U.S. Patent and Trademark Office under 35  
U.S.C. §371 as follows:

**In the Specification:**

Please replace the Specification of the present application, including the  
Abstract, with the following Substitute Specification:

10/070603

11/pbk

DEPT OF PATENTS 08 MAR 2002

## SPECIFICATION

### TITLE OF THE INVENTION

### SYSTEM AND METHOD FOR OPTICAL INFORMATION TRANSMISSION

#### 5 BACKGROUND OF THE INVENTION

Polarization multiplexing, a system and a method for optical information transmission via differently polarized optical signal elements, are used to increase the capacity of an optical transmission system. The Proceedings of the European Conference on Optical Communications 1993, Montreux, Switzerland, pages 401-10 404, Lecture WeP9.3, F. Heismann et al., "Automatic Polarization Demultiplexer for Polarization-Multiplexed Transmission Systems" describe an optical polarization-multiplexed transmission system. A major disadvantage of this configuration is that a receiver-end polarization transformer is controlled such that the two polarization-multiplexed channels are split between the two outputs of a 15 downstream polarization beam splitter. This is done by forming a correlation signal of the recovered clock with the received signal, and through maximizing this by adjustment of the polarization transformer.

The procedure according to the prior art has a number of disadvantages:

First, the correlation product disappears when averaged over time when a 20 pure AC-voltage-coupled pseudo-sequence is applied, thus making the control process difficult or impossible.

Furthermore, different bit rates had to be chosen in order to distinguish between the two polarization-multiplexed channels, which is not feasible in practice. Furthermore, significantly different optical wavelengths had to be chosen, 25 which likewise is unacceptable in practice.

One object of the present invention is, thus, to specify a system and an associated method for optical information transmission, which avoid the disadvantages of the prior art.

### SUMMARY OF THE INVENTION

30 A solution to the problem is to detect any interference which occurs in the two optical, differently polarized polarization-multiplexed signals in a signal

processing module, and to use this to control a controllable polarizing element. This is done by conditioning this interference at the transmission end; that is to say, randomizing it. Corresponding spectral signal elements are minimized by a polarization regulator, so that crosstalk in polarization multiplexing is minimized 5 and, at the same time, the useful signals are at least approximately maximized. All the disadvantages that have been mentioned with the prior art are in this way avoided.

In one exemplary embodiment of the present invention, the polarization-multiplexed signal is produced at the transmission end from a laser signal, which is 10 first of all split between two signal paths and then, in each case, separately intensity-modulated. These signal paths are then combined in a polarization beam splitter, with orthogonal polarizations, with the frequency of the laser being modulated at the same time. Any delay time difference between these paths means that the frequency modulation results in differential phase modulation between the 15 multiplexed signals.

At the receiver end, the signal is split via a coupler between two receiver paths. Input-side polarization control is carried out in each receiver path, followed by a polarizer for suppressing the respectively undesirable polarization-multiplexed channel, a conventional photoreceiver in each case having a photodiode and, 20 finally, electrical data signal regenerators connected downstream from the photodiodes. Spectral signal elements are in each case detected via a filter. These spectral signal elements disappear only when one of the multiplexed signals is completely suppressed by the polarizer. This results in a simple and, at the same time, highly effective control criterion for setting the respective polarization 25 transformer. In this case, each of the regenerators receives and regenerates only one polarization-multiplexed channel, which corresponds to the desired receiver-end separation of the signals. In one embodiment, correlation is carried out, before reaching the filter, preferably with the time derivative of the recovered data signal from the respective other channel. This results in a highly accurate control criterion 30 in order to compensate for polarization mode dispersion.

Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

#### BRIEF DESCRIPTION OF THE FIGURES

- 5      Figure 1 shows a polarization-multiplexed transmitter with only one laser.  
Figure 2 shows a polarization-multiplexed transmitter with two lasers.  
Figure 3 shows a receiver according to the present invention.  
Figure 4 shows a separator/detector.  
Figure 5 shows a variant of a part of the receiver from Figure 3.  
10     Figure 6 shows a vector diagram of linear polarization states.  
Figure 7 shows an embodiment variant of a separator/ detector.  
Figure 8 shows an embodiment variant of a filter unit.  
Figure 9 shows a further embodiment variant of a filter unit.  
Figure 10 shows a further receiver according to the present invention.  
15     Figure 11 shows a variant of a part of the receiver from Figure 10.  
Figure 12 shows a correlating element.  
Figure 13 shows one advantageous refinement of the correlating element.  
Figure 14 shows a further correlating element.

#### DETAILED DESCRIPTION OF THE INVENTION

- 20     In a transmission arrangement as shown in Figure 1, the output signal from a transmission laser LA is split between two optical waveguides, with approximately the same power levels, via a transmission-end power splitter PMC. Any optical and/or electrical amplifiers which may be required are omitted here and in the following figures, for the sake of clarity. The transmission-end power splitter PMC may be, for example, a polarization-maintaining fiber coupler. The signals obtained in this way are passed through a respective modulator MO1, MO2, which is preferably in the form of an intensity modulator or else, for example, a phase modulator, and where transmission-end modulation signals SDD1 and SDD2, respectively, are applied, thus producing optical signal elements OS1, OS2.  
25     These are modulated. OS1 is a first optical signal element, and OS2 is a second optical signal element. These are combined, preferably with orthogonal  
30     signals.

polarizations, via a transmission-end polarization beam splitter PBSS. A simple optional directional coupler also can be used instead of the transmission-end polarization beam splitter PBSS.

Polarization-maintaining optical waveguides, for example, likewise can be  
5 provided for the connections between the modulators MO1, MO2 and the transmission-end polarization beam splitter PBSS, with one of these optical waveguides being twisted through 90°. As an alternative to this, a mode converter can be provided in one of these connections.

In order to achieve the desired coherence between the optical signal  
10 elements, OS1, OS2 after combination, differential phase modulation DPM is provided between these two optical signal elements OS1, OS2, and is produced by a phase-difference-modulating device. First phase-difference-modulating devices PDM1, PDM2, PDM12, PDM21, which can be used alternatively or additively, are angle modulators PHMO1, PHMO2 for one of the optical signals, OS1, OS2, or  
15 differential angle modulators PHMO12, PHMO21. In this case, the word differential refers to the angle modulation taking place between the polarized optical signal elements OS1, OS2, which are ideally orthogonal to one another. The frequency shift which may be produced in this case results in a frequency difference FD in the output optical waveguide. Frequency shifters, including  
20 differential frequency shifters, which are suitable for use as the first phase-difference-modulating devices PDM1, PDM2, PDM12, PDM21 may operate, in particular, acousto-optically, or electro-optically, and preferably with full mode conversion, in the case of the phase-difference-modulating devices PDM1, PDM2, PDM12, which is not used for power splitting at the same time. A transmission-end power splitter PMC also can be used as the phase-difference-modulating device PDM21; for example, in the form of an acusto-optical mode converter which operates as a frequency shifter and with half power conversion. This is followed by a polarization beam splitter. In a further exemplary embodiment of a polarization-multiplexed transmitter, the transmission laser LA has an optical frequency  
25 modulation signal FMS applied to it which is produced from a further phase-difference-modulating device PDM0. By way of example, sinusoidal optical

frequency modulation FM with a frequency shift of a few hundred MHz has scarcely any effect on the transmission bandwidth of a 10 Gb/s transmitter. If the magnitude of the delay time difference  $|DT1-DT2|$  between the optical delay times DT1, DT2 of the optical signal elements OS1, OS2 which pass through the modulators MO1, MO2 between the transmission-end power splitter PMC and the transmission-end polarization beam splitter PBSS is chosen not to be zero, the frequency modulation is converted to the desired differential phase modulation DPM of the optical signal elements OS1, OS2 downstream from the transmission end-polarization beam splitter PBSS. This has a spectrum which depends on that of the optical frequency modulation FM.

In the simplest case, the external optical frequency modulation FM may even be dispensed with, by making use, instead of this, of the natural frequency fluctuations from the transmission laser LA, its line width. These frequency fluctuations also lead, via the magnitude of the delay time difference  $|DT1-DT2|$  between the optical delay times DT1, DT2, to differential phase modulation, DPM between the optical signal elements, OS1, OS2.

Furthermore, differential phase modulation DPM is used between the optical signal elements OS1 and OS2 even when, as an alternative to signal 1, a transmission arrangement as shown in Figure 2 is used, with two optical transmitters TX1, TX2. The optical transmitters TX1, TX2 transmit the orthogonal-polarized optical signal elements OS1, OS2, which are combined in a transmission-end polarization beam splitter PBSS. In this case, the optical transmitters TX1, TX2 interact with the transmission-end polarization beam splitter PBSS as a further phase-difference-modulating device PDML. The differential phase modulation DPM produced in this way is added to form a steady-state difference phase angle EPS, which occurs at a specific time between the optical signal elements. The optical transmitters TX1, TX2 are modulated with transmission-end modulation signals SDD1 for the optical transmitter TX1 and SDD2 for the optical transmitter TX2.

The aim of the transmission arrangements shown in Figure 1 and Figure 2, is in each case, to randomize the interference phase angle; that is to say, for

example, if there is a frequency difference FD between the optical signal elements OS1, OS2 the cosine function and the sine function of the differential phase modulation DPM between the optical signals OS1 and OS2 always have a mean value of zero, so that input-side control signals L1, L2, L12, which are obtained in  
5 a way which will be described later, are independent of the steady-state difference phase angle EPS.

Figure 2 also shows the principle of one design of a transmission system using polarization multiplexing. Once the optical signal elements OS1, OS2 have been combined by the transmission-end polarization beam splitter PBSS, the  
10 signals can be transmitted via an optical waveguide LWL to a receiver RX with an input EI. Since the optical waveguide LWL generally does not maintain the polarization, this makes it difficult to separate the two optical signal elements OS1, OS2 once again.

According to Figure 3, the receiver RX includes, for example, a  
15 separator/detector SD and downstream receiver electronics.

Figure 4 shows a separator/detector SD for polarization multiplexing. The received optical signal elements are passed from the input EI to a controllable polarizing element SUB. This contains a controllable polarization transformer PT, which is preferably designed to be endless, and receives at least one first output-side control signal ST1, and preferably a second output-side control signal ST2, as  
20 well. Both the first output-side control signal ST1 and the second output-side control signal ST2 may consist of one or more signals. A fixed polarizing element EPBS is fitted at the output of the polarization transformer PT and may be in the form of a polarization beam splitter which produces first and second signal components OUT1, OUT2 at its outputs. Ideally, the signal components OUT1, OUT2 should be the orthogonal-polarized optical signal elements OS1 and OS2, respectively. However, this is true only if the controllable polarization transformer PT is adjusted in a suitable manner. This contains a first input-side polarization transformer PMDC, which is designed to be suitable for PMD compensation and is  
25 referred to as a PMD compensator, and is controlled by output-side control signals STW1, STW2, which are designed to control it, and contains an output-side  
30

polarization transformer SPT, which follows it in the propagation direction of the optical signals OS1, OS2 and is controlled by control signals ST1, ST2, which are designed to control it. When, on the other hand, the controllable polarization transformer PT is not set optimally, crosstalk results due to the respectively undesired optical signal element OS2 or OS1. One idea of the present invention is to detect the interference INT1 and INT2 which respectively occurs in this case in the two optical signal elements OS1, OS2. This interference INT1 and INT2, respectively, occurs in these signal components, OUT1 and OUT2, respectively, in this case by virtue of the optical field strength or the optical power.

10 The respective signal components OUT1 and OUT2 are detected in respective photodetectors PD11 and PD21, which produce a first detected signal ED1 and a second detected signal ED2. These, in turn, contain the respective interference INT1 and INT2, but in this case by virtue of the photocurrents of the respective photodetectors PD11 and PD21.

15 The input-side polarization transformer PMDC, that is to say the PMD compensator PMDC, may be designed, for example, as described in German Patent Applications 19841755.1 and 19830990.2. A version with an at least approximately frequency-independent controllable polarization transformer is likewise of interest, which is followed by a highly frequency-dependent, fixed 20 polarization transformer which, for example, has only first-order polarization mode dispersion. The latter may be formed from a piece of polarization-maintaining fiber with a differential group delay time between two modes. Arrangements such as these are known from IEEE J. Lightwave Technology, 17(1999)9, pages 1602-1616, and the references quoted there. The controllable polarizing element SUB, or 25 parts of it, in particular the controllable polarization transformer PT, may be integrated on a substrate which is composed, for example, of lithium niobate. Instead of the integrated design, the input-side polarization transformer PMDC could be omitted, with the output-side polarization transformer SPT and the fixed polarizing element EPBS, which is in the form of a polarization beam splitter, 30 being designed as described in the Proceedings of the European Conference on Optical Communications 1993, Montreux, Switzerland, pages 401-404, Lecture

WeP9.3. Embodiments according to the subject matters described in German Patent Applications 19858148.3 and 19919576.5 are also possible.

The detected signals ED1, ED2 are preferably passed to digital receivers D1, D2, as shown in Figure 3. These may contain decision makers and clock recovery units and may emit data output signals DD1, DD2 which, ideally, are logically identical to the transmission-ended modulation signals SDD1 and SDD2, respectively.

The detected signals ED1, ED2 are passed to a signal processing module DR. In principle, instead of this, the signal components OUT1, OUT2 leaving the controllable polarizing element SUB also can be passed directly to this signal processing module DR. It should then be designed to process these signal components OUT1, OUT2, and the photodetectors PD11, PD21 may be omitted.

This signal processing module DR detects any interference INT1, INT2 which occurs between the optical signal elements OS1, OS2, and also may contain regulators RG1, RG2. Signals EDV1, EDV2 which are in the form of detector signals ED1, ED2 and can be processed are processed for this purpose in the signal processing module DR. This emits an output-side control signal ST1, ST2, which drives the output-side polarization transformer SPT1, SPT2. These signals EDV1, EDV2, which can be processed, are passed to respective filters LED1 and LED2 for this purpose. In order to keep the complexity low, it is, for example, possible to measure the current at that electrode of a photodiode at which the data signal is not tapped off. This results in the advantage that the data signals are not corrupted, and that the desired filtering is at least partially carried out at this stage by the capacitive blocking to ground produced at the other electrode of the photodiode. In this case, detected signals ED1, ED2 each include a broadband data signal on one line, and a low-frequency signal on another line. The former is processed further in the digital receiver D1 or D2, respectively, while the latter is supplied to the respective filter LED1 or LED2.

As an alternative to this, the broadband data signal on one line and the low-frequency data signal on another line may each originate from two different

photodiodes which, together with in each case one upstream further optical beam splitter, form the respective photodetector PD11 or PD21.

The filters LED1, LED2 are preferably designed as bandpass filters, with a low frequency in comparison to the symbol rate, and thus select spectral signal elements FIO1, FIO2 in whose frequency bands interference INT1, INT2 between the optical signal elements OS1 and OS2 occurs due to the specific configuration of the transmission apparatus, as shown in Figures 1 or 2, in the controllable polarizing element SUB. In the case of optical frequency modulation FM, this is, in each case, the modulation frequency MO, which is not identical to the frequency 5 modulation shift of, for example, 1 MHz, or the other modulation frequencies in the range from about 0.1 Hz to 1 GHz are at least, in principle, suitable. Multiples n\*MO of the modulation frequency where n is an integer also may be evaluated on their own or together with it. The filters LED1, LED2 are preferably in the form of bandpass filters. It is likewise possible for them to be in the form of low-pass 10 filters, with the DC component being passed through. In the case of an a periodic frequency modulation signal FMS or a frequency difference FD, which fluctuates severely through the line widths of the optical transmitters TX1, TX2, between the optical signal elements OS1, OS2, the filters LED1, LED2 preferably can pass the spectral maximum of the interference INT1, INT2 in the detected signals ED1, 15 ED2.

The selected spectral signal elements FIO1, FIO2 at the outputs of the filters LED1, LED2 are passed to detectors DET1 and DET2, respectively, which, possibly after low-pass filtering in the low-pass filters LPF1, LPF2, produce input-side control signals L1, L2. These detectors DET1, DET2 may be in the form of 20 root mean square value detectors, or power detectors. By definition, in the case of power detectors, the second-order moment SOMD1, SOMD2 of the corresponding spectral signal element FIO1, FIO2 is evaluated. The input-side control signal L1, L2 is then a linear function F of this second-order moment SOMD1, SOMD2. In the case of root means square value detectors, the input-side control signal L1, L2 25 is a square-root function F of this second-order moment SOMD1, SOMD2 of this spectral signal element FIO1, FIO2. Peak value detectors or similar devices also

may be used, especially if the spectral signal element FIO1, FIO2 is essentially at a signal frequency whose peak value is at least approximately a square root function F of the power; that is to say, of this second-order moment SOMD1, SOMD2 of this spectral signal element FIO1, FIO2. The input-side control signals L1, L2 are  
5 passed to regulators RG1, RG2, whose output signals are used as output-side control signals SD1, SD2 for driving the controllable polarizing element SUB in the separator/detector SD; in this case, the polarization transformer PT contained in it. The regulators RG1, RG2 are designed such that the input-side control signals L1, L2 assume minimum magnitudes; that is to say, minimum interference INT1,  
10 INT2 is indicated between the optical signal elements OS1 and OS2. This ensures optimum receiver operation.

The signal processing module DR, according to the present invention and as already described, of the receiver RX in Figure 3 also can be embodied via a further variant of the present invention illustrated in Figure 5. This is possible in situations  
15 in which a separator/detector SD with a controllable polarizing element SUB is provided, which on the output side emits signal components OUT1, OUT2 which correspond at least approximately to orthogonal components of the signal elements OS1, OS2 passed to it; that is to say, for example, which has a controllable polarization transformer PT followed by a polarization beam splitter as a fixed  
20 polarizing element EPBS, as shown in Figure 4. Since the interference INT1, INT2 and, if the same frequency bands are chosen, the spectral signal elements FIO1, FIO2 as well are then always in antiphase in the two receiver paths (assuming that the electrical signal polarities of the receiver paths are the same) the difference between the first and second signals, EDV1, EDV2, which are in the form of first  
25 and second detected signals ED1, ED2, respectively, and can be processed, is processed respectively as further detected signals ED1-ED2 and, at the same time, as a further signal EDV12 which can be processed, in a first subtractor SUBED12 for situations such as this, in Figure 5. This is supplied to a filter LED12, which is designed in the same way as the filters LED1, LED2 and allows a further spectral  
30 signal element FIO12 to pass. This is supplied to a detector DET12, which is designed in the same way as the detectors DET1, DET2 and uses the signal element

to produce a further input-side control signal L12 which, for example, is identical to the second-order moment SOMD12 of this further spectral signal element FIO12. This may be followed by a low-pass filter LPF12, designed in the same way as the low-pass filters LPF1, LPF2. A regulator RG produces output-side control signals ST1 and, possibly ST2. This is designed such that the input-side control signal L12 supplied to it is minimized, so that the interference INT1, INT2 is thus also minimized. In principle, a single further filter LED12 will be sufficient to produce the input signal for the single detector DET12. However, since broadband subtractors SUBED12 are costly, it is generally better to provide filters LED1 and LED2 first of all at the inputs of a correspondingly relatively narrowband first subtractor SUBED12 and, possibly, a further filter LED12 at its outputs which, when cascaded with the respective filter LED1 or LED2, produces the desired spectral form of the difference between the detected signals ED1, ED2.

The regulators RG1, RG2, RG in Figures 3 and 5 preferably operate on the basis of a lock-in method and preferably have integral or proportional-integral control elements. The regulators RG1, RG2, RG also may, possibly, be omitted, so that one input-side control signal L1, L2, L12 is at the same time used as the output-side control signal ST1, ST2.

Both the input-side control signals L1, L2, L12 and the output-side controls signals ST1, ST2 of the regulators RG1, RG2, RG are control signals L1, L2, L12, ST1, ST2.

If the optical frequency modulation FM is produced by (preferably sinusoidal) direct modulation of a semiconductor laser, the optical signal elements OS1, OS2 have not only the desired differential phase modulation DPM produced by optical frequency modulation FM and having a shift ETA (which in the following text is regarded as the peak shift in radians), but also undesirable amplitude modulation. This is not dependent on the polarization states chosen at the receiver end and, thus, it is harder to set the polarizations in controllable polarizing elements, SUB, SUB1, SUB2; in particular, in controllable polarization transformers PT, PT1, PT2. In cases such as this, it may be worthwhile evaluating multiples  $n^*OM$ , for example  $n = 2, 3, 4, \dots$ , of the modulation frequency OM.

At least in the case of sinusoidal frequency modulation FM, the amplitudes of even ( $n = 0, 2, 4, \dots$ ) and odd ( $n = 1, 3, 5, \dots$ ) multiples  $n*OM$  of the modulation frequency OM, detected at the receiver end, are proportional to the cosine and sine, respectively, of steady-state difference phase angle EPS, which is sensitively  
 5 dependent on the magnitude of the delay time difference  $|DT1-DT2|$  between the optical delay times DT1, DT2.

However, according to the present invention, it is possible to evaluate at least one even multiple of the modulation frequency OM, and at least one odd multiple of the modulation frequency OM, at the same time. Provided the filter or  
 10 filters LED1, LED2, LED12 are designed in a suitable manner, the respective filter output power is a second-order moment SOMD1, SOMD2, SOMD12, and the input-side control signals L1, L2, L12 is/are thus also proportional to  $\cos^2(EPS)+\sin^2(EPS) = 1$ ; that is to say, independent of the steady-state difference phase angle EPS. LOMn is assumed to be a power transmission factor  
 15 for the multiple  $n*OM$ . In a first such example, the modulation frequency OM, corresponding to the Bessel line J1, where Jn is an n-th order Bessel function of the first kind, and twice the modulation frequency  $2*OM$ , corresponding to the Bessel line J2, are passed through filters LED1, LED2, LED12, and the detectors DE1, DET2, DET12 are power detectors or root mean square value detectors.  
 20 LOM1\*J1(ETA)^2 is set to be LOM2\*J2(ETA)^2, and is achieved, at least approximately, for example, by  $|J1(ETA)| = |J2(ETA)|$  where ETA = 2.63 and LOM1=LOM2.

The further refinement of the principle of the present invention on which this embodiment is based is that the detected (or even the detectable, provided the  
 25 detection process is independent of frequency) first power PEVEN or second power PODE, which is measured by detection of only even or only odd multiples of the modulation frequency OM in the input-side control signal L1, L2, L12, has a sum PEVEN+PODD which is independent of the steady-state difference phase angle EPS. It also has the same expected values.

30 Further exemplary embodiments based on this principle are described below:

It is possible for the modulation shift ETA to be subjected to fluctuations over the course of time; for example, due to aging of the laser. In order, nevertheless, to make it possible to keep the detection process independent of the difference phase angle EPS, to a first approximation, the input-side control signals  
5 L1, L2, L12 must, to a first approximation, be independent of the modulation shift ETA. This is achieved, for example, via filters LED1, LED2, LED12, which are in the form of bandpass filters and each pass the modulation frequency OM, twice this frequency 2\*OM, and three times this frequency 3\*OM. The power transmission factor values required to do this are at least approximately LOM1=0.72852\*LOM2  
10 and LOM3=1.6036\*LOM2, and ETA is chosen to be at least approximately 3.0542.

As mentioned above, detection using the single modulation frequency OM may result in problems, so that it may be better to carry out the detection process at 2\*OM, 3\*OM, 4\*OM instead. The power transmission function values required in this case are at least approximately LOM2=0.64066\*LOM3 and  
15 LOM4=1.3205\*LOM3 and ETA is chosen to be at least approximately 4.2011. Those power transmission factors which have not been mentioned, that is to say in the present example LOM0, LOM1, LOM5, LOM6, LOM7, ... for frequencies 0, OM, 5\*OM, 7\*OM, ..., are in each case assumed to be at least approximately equal to zero.

20 If amplitude modulation also occurs in addition to the optical frequency modulation FM, the required power transmission factors LOMn ( $n = 0, 1, 2, \dots$ ) may differ from the values quoted above, to be precise with the difference increasing with the level of amplitude modulation.

It can be difficult to design bandpass filters such as these. In a further  
25 embodiment of the present invention, a number of filters, or else individual filters LEDOMn, which are preferably in the form of bandpass filters, can be provided for frequencies  $n*OM$ , since these signals are mathematically orthogonal at the frequencies  $n*OM$ , so that their individual power levels can be added directly, without any cross-power terms. These filters LEDOMn each have a detector  
30 DETOMn connected to them, preferably in the form of a power measurement device. One embodiment such as this of the elements illustrated in Figures 3 and 5,

namely filters LED1, LED2, LED12, detectors DET1, DET2, DET12 and low-pass filters LPF1, LPF2, LPF12, which can be combined to form filter units FE1, FE2, FE12, is shown in Figure 8. Here, in a corresponding way to that in the last exemplary embodiment,  $n = 2, 3, 4$ , but it is likewise possible to select different values of  $n$ . The filter unit FE12, which is implemented as an alternative in Figure 8, also may include the subtractor unit SE in which case linear function blocks can be shifted or split in accordance with the commutative or distributive law.

The splitting is carried out on filters LEDOM $n$  where  $n$  is an integer. The output signals from these filters LEDOM $n$  are spectral signal elements FIOOM $n$  where  $n$  is an integer, and are essentially composed of spectral components at the frequencies  $n^*OM$ . These spectral signal elements FIOOM $n$ , where  $n$  is an integer, are passed to detectors DETOM $n$ , where  $n$  is an integer. The power transmission factors LOM $n$  are each obtained by multiplication of the power transmission factor of a filter LEDOM $n$  by that of a weight Gn, which is part of the associated detector DETOM $n$ , or is downstream from it. The weight Gn may be provided from a potentiometer. At the latest after the weighting by the weight Gn, a second-order moment SOM $n$  is obtained in each case, where  $n$  is an integer, namely the power of the spectral signal element FIOOM $n$ . This second-order moment SOM $n$  is added to the respective power transmission factor LOM $n$  in an adder ADD. In this case, according to the present invention, a first power PEVEN of at least one spectral component where  $n$  is even, and a second power PODD of at least one spectral component where  $n$  is odd, are added. The desired input-side control signal L1, L2 or L12 is produced at the output of the adder ADD and, possibly, after passing through a low-pass filter LPF1, LPF2, LPF12, in a corresponding way to the exemplary embodiments of filter units FE1, FE2 or FE12 in Figures 3 or 5, which, according to the present invention, is once again independent of the steady-state difference phase angle EPS and, to a first approximation, is independent of the modulation shift ETA, since it is a constant sum PEVEN+PODD of the first power PEVEN of even spectral components, and of the second power PODD of odd spectral components.

- The input-side control signal L1, L2, L12 is a function F of the second-order moment SOM<sub>n</sub> of these spectral signal elements FIOOM<sub>n</sub>, which is linear; namely, the weighted sum of the individual power levels of these spectral signal elements FIOOM<sub>n</sub>. Detection and addition also may be interchanged. In this case,
- 5 the detectors DETOM<sub>n</sub> and possibly weights G<sub>n</sub> in Figure 8 must be replaced by through-links while a detector DET1, DET2, DET12 which was not required until now in Figure 8 and, therefore, could be replaced by a through-link until now and which is a power or a root mean square value detector, is provided downstream from the adder ADD.
- 10 In practice, it is advantageous for the filter units FE1, FE2, FE12 according to Figure 8 or parts of Figures 3 and 5 to be provided by digital signal processing using a microprocessor. This microprocessor also may provide the regulators RG, RG1, RG, or parts of them.
- 15 Further variations of the principle of the present invention are feasible by providing different time profiles for differential phase modulation, DPM between the two optical signal elements OS1, OS2. Such time profiles are preferably designed such that an input-side control signal L1, L2, L12 is as independent as possible of the amplitude of the differential phase modulation DPM or of optical frequency modulation FM, which produces the phase modulation, in a transmission
- 20 laser LA.
- In practice, sinusoidal current modulation as a frequency modulation signal FMS for a transmission laser LA in any case results in non-sinusoidal frequency modulation FM and, hence, in non-sinusoidal differential phase modulation DBM between the optical signal elements OS1, OS2. There is thus no pure Bessel spectrum in the detected signals ED1, ED2; in particular, the modulation frequency OM is generally strongly represented. In order, in contrast to the situation described above, for there to be no need to change their higher harmonics n\*OM, for example up to n = 4, suitable second-order moments SOM<sub>n</sub> of the spectral signal elements DETOM<sub>n</sub> and/or possibly mixed second-order moments SOM<sub>m,n</sub>,
- 25 where m, n are integers, may be defined between them.
- 30

Figure 9 once again shows a filter unit FE1, FE2, FE12, to which a detected signal ED1, ED2, ED1-ED2 is passed. A filter LED with a downstream detector DET is provided, which is in the form of a microprocessor with an input-side analogue/digital converter. This detector DET is used to calculate the Fourier components relating to the modulation frequency OM and twice this frequency 2\*OM, as spectral signal elements FIOOM1, FIOOM2, which can be carried out as filtering in filters LEDOM1, LEDOM2, which are in the form bandpass filters, within a filter LED. Owing to the formation of the mixed second-order moment SOM12, the two spectral signal elements FIOOM1, FIOOM2 preferably already have had removed from them their delay time, which results from the fact that the formation of the Fourier coefficients does not necessarily coincide in time with the oscillation of the frequency modulation FM. If, for example, a Fourier component FIOOM1 of the spectral signal element at the modulation frequency OM has a complex phase vector, then all the determined Fourier components FIOOM1, FIOOM2, ... FIOOMn are multiplied by the 1st, 2nd, .. n-th power of the complex conjugate of this phase vector, in accordance with the shift rule for Fourier transformation. A weighted sum of the second-order moment SOM1, SOM2, SOM12 of these two spectral signal elements FIOOM1, FIOOM2 and of the mixed second-order moment is formed between these two spectral signal elements FIOOM1, FIOOM2, and is used as the input-side control signal L1, L2, L12. The weights used in this case are at the same time the corresponding power transmission factors LOM1, SOM2, LOM12 of these second-order moments SOM1, SOM2, SOM12. They are chosen to produce an input-side control signal L1, L2, L12 which is independent of the steady-state difference phase angle EPS.

This can be done by inversion of a 3x3 matrix.

If a pure Bessel spectrum is present, the power transmission factor LOM12 of the mixed second-order moment SOM12 is chosen to be equal to zero and, as mentioned above,  $LOM1^*J1(\eta)^2$  is set to be  $LOM2^*J2(\eta)^2$ , as is achieved, at least approximately, for example, via  $|J1(\eta)| = |J2(\eta)|$  where  $\eta = 2.63$  and  $LOM1 = LOM2$ . In practice, in contrast, the distortion which occurs in the optical frequency modulation FM generally requires that a power

transmission factor LOM12 other than zero be required for the mixed second-order moment SOM12 and this may even be negative or complex. As an extension to this exemplary embodiment, in addition to the spectral signal elements FIOOM1, FIOOM2, further spectral signal elements FIOOMn, second-order moments SOMn  
 5 relating to them and all the possible mixed second-order moments SOMmn, where m, n are integers, may be formed between, in each case, one spectral signal element FIOOMm and another spectral signal element FIOOMn and, weighted with weights, may be added to form an input-side control signal L1, L2, L12, so that this results in an input-side control signal L1, L2, L12 which is independent of the  
 10 steady-state difference phase angle EPS. Optical weights, which also take account of the signal-to-noise ratios in the individual spectral signal elements FIOOMn, can be determined here, for example, by linear programming using the simplex method. This relates, in particular, to the spectral signal element FIOOM3 at three times 3\*OM the modulation frequency OM as well as to the spectral signal element  
 15 FIOOM0, which represents a DC signal and may have a constant offset, at zero times 0\*OM the modulation frequency OM.

In order to obtain an uncorrupted input-side control signal L1, L2, L12 despite any parasitic amplitude modulation which may be present, those essentially constant components of the spectral signal elements FIOOM1 and, possibly,  
 20 FIOOM2, FIOOM3, ..., which are caused by this amplitude modulation can be subtracted before further processing of these spectral signal elements FIOOM1 and, possibly, FIOOM1, FIOOM3, ... .

Reduced orthogonality in the received optical signal elements OS1, OS2 can occur by non-ideal multiplexing at the transmission end, in the transmission-end polarization beam splitter PBSS, or as a result of polarization-dependent attenuation or amplification in the optical waveguide LWL. As shown in Figure 6 and Figure 7, it is advantageous in cases such as these to provide a further controllable polarizing element SUB1, SUB2 in each case, with power splitting being provided via a receiver-end power splitter TE, which may be part of the  
 25 further controllable polarizing elements SUB1, SUB2, or may be upstream of them. In Figure 7, these further controllable polarizing elements SUB1, SUB2 are further  
 30

controllable polarization transformers PT1, PT2. These contain in each case one further input-side polarization transformer PMDC1, PMDC2, which is designed to be suitable for PMD compensation, and is referred to as PMD compensator, which is controlled by, in each case, at least one output-side control signal STW1, STW2,  
5 which is designed to control it, and in each case one output-side polarization transformer SPT1, SPT2, which is downstream from it in the propagation direction of the optical signals OS1, OS2 and is controlled by in each case at least one control signal ST1, ST2, which is designed to control it. Instead of or in addition to these further input-side polarization transformers PMDC1, PMDC2, which are  
10 designed to be suitable for PMD compensation, it is possible, upstream of the receiver-end power splitter TE, to use the first input-side polarization transformer PMDC, which is designed to be suitable for PMD compensation. These further controllable polarization transformers PT1, PT2 are followed by a respective downstream further, first and second fixed polarizing element EPBS1, EPBS2,  
15 which may be in the form of polarization beam splitters or polarizers. The further controllable polarizing elements SUB1, SUB2, or parts of them, may once again be integrated on the substrates. The input-side polarization transformers PMDC, PMDC1, PMDC2 initially may not be present and may be replaced by through-links, so that the input EI of the separator/detector SD is connected directly to the  
20 receiver-end power splitter TE. The polarization matching processes which are achieved according to the present invention by the exemplary embodiment shown in Figure 7 are sketched in Figure 6, for linear polarization situations. The received optical signal elements OS1, OS2 are, in this example, not polarized orthogonally with respect to one another. The first signal component OUT1, which is  
25 transmitted by the first fixed polarizing element EPBS1, is, however, in this case orthogonal to the second optical signal element OS2, and the second signal component OUT2, which is transmitted by the second fixed polarizing element EPBS2, is in this case orthogonal to the first optical signal element OS1. In order to achieve the settings shown in Figure 6, it is preferable to use the refinement of  
30 the signal processing module DR shown in Figure 3.

Depending on the way in which the differential phase modulation DPM is produced between optical signal elements OS1 and OS2, the signal processing module DR and, in particular, the filters LED1, LED2, LED12 and the detectors DET1, DET2, DET12 may be varied to an even greater extent. Yet, when the magnitude of the delay time difference between the optical delay times DT1, DT2 is  $|DT1-DT2|$ , the optical frequency modulation FM is not used, and the differential phase modulation DPM is produced by natural frequency fluctuations of the transmission lasers LA, then the filters LED1, LED2, LED12 should be designed such that major parts of the resultant interference spectrum, which generally extends over a number of MHz, are passed through. If, as is shown in Figure 1, angle modulators PHMO1, PHMO2 or a differential angle modulator PHMO12 is or are used, and this or these is or are in the form of frequency shifter or differential frequency shifter, or if, as is shown in Figure 2, optical transmitters TX1, TX2 at different frequencies are used, then the filters LED1, LED2, LED12 must be matched to the resultant difference frequency FD between the optical signal elements OS1 and OS2. Acousto-optical and electro-optical components, for example, may be used as frequency shifters or differential frequency shifters. As an alternative to this, phase modulators or a differential phase modulator may be used as angle modulators PHMO1, PHMO2 or as a differential angle modulator PHMO12, and this or these is or are driven so as to produce differential phase modulation DPM, which is at least partially linear as a function of time, and with the time derivative of the differential modulation phase being  $2*\pi$  times the frequency difference FD. These are, for example, phase modulators based on the Serrodyne principle, with a sawtooth phase shift.

If the angle modulators PHMO1, PHMO2 or the differential angle modulator PHMO12 are or is in the form of phase modulators or a differential phase modulator with sinusoidal differential phase modulation DPM, this in contrast results in a Bessel spectrum, as in the case of sinusoidal optical frequency modulation FM, whose detection already has been considered further above.

Finally, signals which are used for checking and, possibly, for slow readjustment or deliberate pre-emphasis of the transmission-end polarization

orthogonality, can be obtained by measuring the power levels of the detected signals ED1, ED2 or by reading the residual component, which remains despite the stabilization of the polarization transformer PT, of the further regulator input signal L12, which is obtained from the difference between the first detected signal ED1  
5 and the second detected signal ED2. This allows the transmission system to be optimized such that, for example, polarization-dependent attenuation in the optical waveguide not only does not lead to any crosstalk, but also does not lead to any adverse affect on one of the optical signal elements OS1, OS2 in comparison to the other.  
10 In addition, for example by applying further optical frequency modulation, or by using natural optical frequency modulation contained in the spectrum of the transmission laser LA, for example at a frequency other than the modulation frequency OM, or by evaluation of the regulator signals, it is possible to obtain information which, for example, allows adaptive control of the modulation shift  
15 ETA or of power transmission factors LOMn.

In an arrangement as shown in Figure 9, it is particularly advantageous to determine the expected values of a number of moments, or of all the moments, SOM1, SOM2, ..., SOMn, SOM12, ... SOMmn that occur in the spectral signal elements FIOOMn where n is an integer. Specifically, this allows the modulation  
20 shift ETA to be calculated. The frequency modulation signal FMS, and hence the optical frequency modulation FM can be set on the transmission laser LA via a return channel, so as to achieve an optimum signal-to-noise ratio for the regulator input signal L1, L2, L12 that is obtained. Slow thermal frequency modulation of a transmission laser A that is formed by a semiconductor is suitable, for example, as  
25 additional frequency modulation to allow the formation of these expected values.

Overall, the previous exemplary embodiment of the present invention preferably relates to the adjustment of an output-side polarization transformer SPT, SPT1, SPT2, which cannot compensate, or can compensate only to a minor extent, for any polarization mode dispersion which may occur. The following exemplary  
30 embodiments of the present invention preferably relate, in contrast, to the adjustment of an input-side polarization transformer PMDC, PMDC1, PMDC2,

which is suitable for PMD compensation. The optical complexity is minimized if the control signals for the PMD compensator PMDC in Figure 4 or the PMD compensators PMDC1 and PMDC2 in Figure 7 are derived from the first and second detected signal ED1, ED2. This is done, for example, by simple electrical  
5 spectral analysis; attenuation of high-frequency signal components indicates uncompensated PMD, and can be avoided by suitable adjustment of an input-side polarization transformer PMDC, PMDC1, PMDC2.

In one advantageous embodiment of the present invention, the receiver RX as shown in Figure 10 may have a further signal processing module DRW instead  
10 of the signal processing module DR or, preferably, in addition to it. On the input side, the further signal processing module receives the detected signals ED1, ED2 which are passed to a respective first correlation input EIME11, EIME21 of a correlating element ME1, ME2. The data output signal DD2, DD1, which is obtained from the respective other detected signals ED2, ED1, is passed to a  
15 respective second correlation input EIME12, EIME22 of the correlating elements ME1, ME2. A further signal EDW1, EDW2, which is in the form of a correlation signal and can be processed, is produced by a respective output of the correlating element ME1, ME2. These further signals EDW1, EDW2, which can be processed, are passed to further filter units FEW1, FEW2, which are designed in the same way  
20 as the above-mentioned filter units FE1, FE2, FE12. On the output side, these filter units FE1, FE2, FE12 emit further input-side control signals, LW1, LW2, which are passed to further regulators, RGW1, RGW2, which are designed in the same way as the abovementioned regulators RG1, RG2. On the output side, these further regulators RGW1, RGW2 emit further control signals, STW1, STW2 for  
25 controlling the input-side polarization transformers PMDC1, PMDC2, PMDC.

The further signal processing module DRW in the receiver RX in Figure 10 may be in the form of a further variant of the present invention, as shown in Figure 11. This is preferably possible in situations in which there is only one common input-side polarization transformer PMDC. Analogously to Figure 5, an additional  
30 signal EDW12, which is in the form of a correlation signal and can be processed, is produced from the further signals EDW1, EDW2, which are in the form of

correlation signals and can be processed via a further subtractor SUBEDW. This signal EDW12 is passed to a further filter unit FEW12, which may be designed in the same way as the filter units FE1, FE2, FE12, FEW1, FEW2. On the output side, this emits a further input-side control signal LW12, which is supplied to a further regulator RDW which can be designed in the same way as the regulators RG1, RG2, RG, RG1, RG2 and emits the further output-side control signal STW1, STW2. The correlating elements ME1, ME2 and the further subtractor SUBEDW which is connected to its outputs can be combined to form a correlating subtraction unit SEW, although this also may be designed differently.

Figure 14 shows an example of a different embodiment of the correlating subtraction unit SEW. The detected signals ED1, ED2 are subtracted in a further subtractor SUBEDW12 which, in principle, can be designed in the same way as the first subtractor SUBED12 but, owing to the subsequent correlation, should be designed to have a sufficiently broad bandwidth so that a further detected signal ED1-ED2 is produced. This is passed to a first input EIME1 of a further correlating element ME12, which can be designed in the same way as the correlating elements ME1, ME2. The data output signals DD2, DD1 are subtracted in an additional subtractor SUBDD21, resulting in a further data output signal DD2-DD1 which preferably has three values if the data output signals DD2, DD1 have two values. This further data output signals DD2-DD1 is passed to a second input EIME2 of the further correlating element ME12. At its output, the further correlating element ME12 emits the additional signal EDW12 which is in the form of a correlation signal and can be processed.

The design for a correlating element ME1, ME2, ME12 is shown in Figure 12. The detected signal ED1, ED2, ED1-ED2, which contains the interference INT1, INT2, is passed via the first correlation input EIME11, EIME21, EIME1 to a first switching element input EISE1 of a switching element SEE which is preferably in the form of a multiplier. Those components of the interference INT1, INT2 which are to be added to the polarization mode dispersion are preferably produced at the transitions of adjacent information bits in the transmission-end modulation signals SDD1, SDD2, to be precise with polarities which depend on the

direction of these transitions. Thus, in an advantageous refinement of the principle according to the present invention, the received and regenerated data output signal DD2, DD1, which is obtained from the respective other detected signal ED2, ED1, is first of all passed to a spectral forming element SF, via the second correlation input EIME12, EIME22. In the case of the further correlating element ME12, the further data output signal DD2-DD1 is passed, instead of this, to the corresponding second correlation input EIME2. The spectral forming element SF has a further subtractor SUBME, to whose two inputs the respective data output signal DD2, DD1, DD2-DD1 is applied directly, or after being delayed by a delay element DEL.

At its output, which is also one output of the spectral forming element SF, this further subtractor SUBME emits a spectrally formed signal DDSF2, DDSF1, DDSF, which is passed to a second switching element input EISE2 of the switching element SEE. The spectral forming element SF in this exemplary embodiment forms, as the spectrally formed signal DDSF2, DDSF1, DDSF at least approximately a time derivative of the respective data output signal DD2, DD1, DD2-DD1; that is to say, this corresponds to high-pass filtering. The delay element DEL may be designed to have a fixed or a variable delay time. A suitable delay time is, for example, a short time, such as one bit period or less of a transmission-end modulation signal SDD1, SDD2, if distortion is intended to be detected via short differential delay times, or longer delay times, which are equivalent to or exceed one, or even a number of these bit periods, if distortion is intended to be detected via longer differential delay times. Since the respective data output signal DD2, DD1, DD2-DD1 is a digital signal, the delay element DEL likewise may operate in a digital manner; in particular, preferably in binary form if the data output signal DD2, DD1 is binary. For better signal forming, it may, for example, be in the form of a D-flipflop DFF, which is controlled by one flank of a clock signal CL which is supplied. A chain having a number of D-flipflops is also feasible in order to extend the delay time of the delay element DEL. In the case of a three-value data output signal DD2-DD1 on the other hand, an analog version of the delay element DEL is preferable; for example, in the form of a delay line. Since the data output signal DD2, DD1, DD2-DD1 which is supplied to the

correlating element ME1, ME2, ME12 is obtained from the respective detected signal ED2, ED1, ED1-ED2, it is generally delayed only by the unavoidable delay time of the digital receiver or receivers D2, D1 and, since it is further delayed in the spectral forming element SF, in the example in Figure 12 by, on average, half the 5 delay time of the delay element DEL, it is normally necessary to carry out a delay time adjustment process between the signals arriving at the first switching element input EISE1 and the second switching element input EISE2 of the switching element SEE. This can be done via a further delay element DDEL, which delays the respective detected signal ED1, ED2, ED1-ED2 or preferably before it is passed 10 onto the switching element SEE. The switching element SEE, and hence the correlating element ME1, ME2, ME12 emits, on the output side, the signal EDW1, EDW2, EDW12, which is in the form of a correlation signal and can be processed.

Alternative embodiments of the present invention may, in each case, have a number of correlating elements for the detection of each of those components of the 15 interferences INT1, INT2 which indicates the polarization mode dispersion and/or may be spectral forming elements SF in the form of fixed or variable high-pass, bandpass or low-pass filters.

One advantageous practical refinement of the correlating element ME1, ME2, which is particularly suitable when binary data output signals DD2, DD1 are 20 present, is shown in Figure 13. The power supply is provided by a supply voltage U+. The respective detected signal ED1, ED2 is in differential form. After passing through the further delay element DDEL, which, for example, includes two delay lines DDEL1, DDEL2 of equal length, the signal is passed to two differential amplifiers DF1, DF2, which are connected in parallel, with opposite polarities, on 25 the input and output sides. These differential amplifiers DF1, DF2 amplify the respective differential input signal, provided one of two currents I1, I2, which are produced from preferably identical constant current sources, flows through them. However, a first switching transistor TT1 provides a discharge path for the first current I1 when its base is supplied with a data output signal DD2, DD1 (which 30 requires a positive level for this method of operation here) which is obtained from the respective other detected signal ED2, ED1. A second switching transistor TT2

provides a discharge path for the second current I<sub>2</sub>, when its base is supplied with this data output signal DD<sub>2</sub>, DD<sub>1</sub>, which was previously delayed in the delay element DEL and is obtained from the respective other detected signal ED<sub>2</sub>, ED<sub>1</sub> of the first and second detected signals ED<sub>1</sub>, ED<sub>2</sub>. As the difference voltage 5 between preferably identical resistors, R<sub>1</sub>, R<sub>2</sub>, the further signal EDW<sub>1</sub>, EDW<sub>2</sub>, which is in the form of a correlation signal and can be processed, is produced as the differential output voltage from the parallel-connected differential amplifiers DF<sub>1</sub>, DF<sub>2</sub>. A capacitor C, which is fitted between the parallel-connected outputs of the differential amplifiers DF<sub>1</sub>, DF<sub>2</sub>, is already used as a low-pass filter which, at least 10 partially, represents the filter LED<sub>1</sub>, LED<sub>2</sub>. In Figure 13, the further subtractor SUBME, the switching element SEE and the filter LED<sub>1</sub>, LED<sub>2</sub> which is at least partially formed by the capacitor C cannot be separated from one another, which advantageously leads to reduced complexity, and the capability to process a higher data rate.

15       The principle of the present invention can be varied by omitting the spectral forming element SF, by the switching element SEE being other than in the form of a multiplier, by it having at its second input a signal DDSF<sub>2</sub>, DDSF<sub>1</sub>, which is not obtained, or is obtained not only, from that data output signal DD<sub>2</sub>, DD<sub>1</sub> which is obtained from the respective other detected signal ED<sub>2</sub>, ED<sub>1</sub>, but, for example, is 20 also obtained from that data output signal DD<sub>1</sub>, DD<sub>2</sub> which is obtained from the detected signal ED<sub>1</sub>, ED<sub>2</sub> supplied to the first input of the switching element, and/or at least one detected signal ED<sub>1</sub>, ED<sub>2</sub>. Such an example already has been given by the version of the correlating subtraction unit SEW illustrated in Figure 14.

25       The example embodiments of the present invention illustrated in Figures 10 to 14 are based, to the extent described so far, on the data output signals DD<sub>1</sub>, DD<sub>2</sub> which are taken from the digital receivers D<sub>1</sub>, D<sub>2</sub> corresponding to the transmission-end modulation signals SDD<sub>1</sub>, SDD<sub>2</sub>. However, particularly if the input-side polarization transformers PMDC, PMDC<sub>1</sub>, PMDC<sub>2</sub> are set incorrectly, it 30 is possible for this not to be true; for example, because the detected signals ED<sub>1</sub>, ED<sub>2</sub> do not on the one hand correspond approximately to the transmission-end

modulation signals SDD1, SDD2, or because the detected signals ED1, ED2 both correspond to that transmission-end modulation signal SDD1, SDD2. In order to preclude situations such as this, the further regulator RGW1, RGW2, RGW can vary the further output-side control signals STW1, STW2 when cases such as this

5 occur such that the input-side polarization transformer or transformers PMDC1, PMDC2, PMDC is or are changed to different states. This can also result in the necessity to, at the same time, vary the output-side control signals, ST1, ST2 emitted from the regulators RG1, RG2, RG. This is continued in a systematic or random manner until at least one, but preferably both, of the data output signals

10 DD1, DD2 obtained from the digital receivers D1, D2 corresponds or correspond at least approximately to the respective transmission-end modulation signals, SDD1, SDD2. Alternatively, or in addition to this, further methods can be used for determining distortion, referred to as PMD distortion, caused by polarization mode dispersion. Distortion analyzers DANA1, DANA2, to which the detected signals

15 ED1, ED2 are supplied, are provided for this purpose in Figure 10. The distortion analyzers DANA1, DANA2 determine, for example via one or more high-pass or bandpass filters, spectral components of the detected signals, which also can be added up and passed to the further regulator RGW1, RGW2, RGW as, in each case, at least one distortion signal SDANA1, SDANA2. A reduction in the high-

20 frequency spectral components of the detected signals ED1, ED2 indicates incorrect adjustment of the input-side polarization transformer or transformers PMDC, PMDC1, PMDC2, so that it or they can be set by the further regulator RGW1, RGW2, RGW so as to avoid PMD distortion. This type of method, which is used here only as an auxiliary method, to compensate for polarization mode dispersion is admittedly already known, in principle, for example from European Patent Application EP 0 909 045 A2 and from IEEE J. Lightwave Technology, 17 (1999)9, pages 1602-1616; however, the novel feature here is its application to polarization-multiplexed signals. As soon as at least one, but preferably both, of the data output signals DD1, DD2 which are obtained from the digital receivers D1,

25 D2 corresponds or corresponds at least approximately to the respective transmission-end modulation signals SDD1, SDD2, the regulator RGW1, RGW2,

RGW switches over, so that, according to the present invention, the input-side control signal LW1, LW2, LW, which is likewise supplied to it and results from detection of interference INT1, INT2, is used to obtain the output-side control signal or signals STW1, STW2.

- 5        If a further output-side control signal SDW1, SDW2 changes, the polarization transformation of an input-side polarization transformer PMDC, PMDC1, PMDC2 is changed. This generally also requires readjustment of one of the output-side polarization transformers SPT, SPT1, SPT2. In order to carry out this readjustment as quickly as possible, the further regulators RGW1, RGW2 in
- 10      Figure 10, and the further regulator RGW in Figure 11, each form an information transmission signal ITS1, ITS2, ITS in the further signal processing module DRW. In the signal processing module DRW, this signal is, in each case, supplied to the regulators RG1, RG2 in Figure 3 and to the regulator RG in Figure 5, which regulators use these information transmission signals ITS1, ITS2, ITS to change the
- 15      output-side control signals STW1, STW2 emitted by them, in order to readjust the output-side polarization transformers SPT, SPT1, SPT2.

The essence of the present invention is always to detect any interference INT1, INT2 which occurs in the two optical signal elements OS1, OS2. The present invention is, therefore, suitable for all operational situations in which such interference INT1, INT2 occurs. This includes the non-return-to-zero signal format, or NRZ for short. It also relates to the return-to-zero signal format, RZ for short, where RZ pulses of the two polarization-multiplexed channels overlap. If these occur alternately, so that there is always one RZ pulse in one channel between two adjacent RZ pulses in the other channel, there is, however, no interference provided the pulse duration is in each case shorter than half the symbol duration. Nevertheless, the present invention itself can be used usefully in these situations, to be precise for controlling a PMD compensator, which produces the advantageous, interference-free state.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be

made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

## ABSTRACT OF THE DISCLOSURE

A system and method for optical information transmission, wherein interference, which occurs on the input side for differently polarized optical signal elements, between these optical signal elements is detected, a control signal is formed from it and is used to control a polarization transformer with the downstream fixed polarizing element.

**In the Claims:**

On page 32, cancel line 1 and substitute the following left-hand justified heading therefore:

**5 CLAIMS**

Please cancel claims 1-31, without prejudice, and substitute the following claims therefore:

32. A system for optical information transmission having differently polarized optical signal elements, comprising:

10 a controllable polarizing element for emitting at least one of the optical signal elements on an output side; and

at least one signal processing module for detecting any interference occurring between the optical signal elements, and for forming at least one control signal based on the detection for controlling the controllable polarizing element.

15

33. A system for optical information transmission as claimed in claim 32, further comprising, in the at least one signal processing module, at least one regulator having at least one input-side control signal at an input of the regulator, and at least one output-side control signal at an output of the regulator, the output-side control signal being passed by the regulator to the controllable polarizing element.

20  
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34. A system for optical information transmission as claimed in claim 32, further comprising, in the controllable polarizing element, a controllable polarization transformer followed by a fixed polarizing element.

30

35. A system for optical information transmission as claimed in claim 34, further comprising, in the controllable polarization transformer, an input-side polarization transformer suitable for PMD compensation followed by an output-side polarization transformer.

36. A system for optical information transmission as claimed in claim 32, further comprising a phase-difference-modulating device for producing differential phase modulation between the optical signal elements.

5 37. A system for optical information transmission as claimed in claim 36, wherein the differential phase modulation is produced such that the input-side control signal is designed to be at least approximately independent of a steady-state difference phase angle between the optical signal elements.

10 38. A system for optical information transmission as claimed in claim 36, further comprising a transmission laser and a transmission-end power splitter, wherein the phase-difference modulating device produces frequency modulation on the transmission laser, and produces the differential phase modulation between the optical signal elements based on a magnitude of any delay time difference between 15 a splitting of an optical signal from the transmission laser in the transmission-end power splitter and combination with orthogonal polarizations of the optical signal elements formed in this way.

20 39. A system for optical information transmission as claimed in claim 32, further comprising at least one photo detector following the controllable polarizing element, wherein a signal component which is emitted on the output side of the controllable polarizing element is supplied to an input side of the at least one photo detector, the at least one photo detector producing at least one detected signal 25 in which the interference is manifested.

25 40. A system for optical information transmission as claimed in claim 39, further comprising a filter in the at least one signal processing module for passing at least one spectral signal element of at least one signal which can be processed and is produced from the at least one detected signal.

30

41. A system for optical information transmission as claimed in claim 39, further comprising a detector in the at least one signal processing module which at least partially provides the input-side control signal which is one of a linear function and a splitter root function of at least one second-order moment of at least 5 one spectral signal element.
42. A system for optical information transmission as claimed in claim 41, wherein the detector produces a second-order moment, which is in mixed form, of two different spectral signal elements.
- 10 43. A system for optical information transmission as claimed in claim 41, wherein the detector produces a second-order moment of a spectral component which is a measure of power of the spectral component.
- 15 44. A system for optical information transmission as claimed in claim 40, wherein the filter passes a Fourier coefficient of a signal, which can be processed, as a spectral signal element, in which case delay time compensation can be effected before formation of second moments in mixed form.
- 20 45. A system for optical information transmission as claimed in claim 40, wherein the at least one signal processing module processes the at least one detected signal and emits an output-side control signal which drives an output-side polarization transformer in the controllable polarizing element.
- 25 46. A system for optical information transmission as claimed in claim 40, further comprising a correlating element in the at least one signal processing module, the correlating element for correlating the at least one detected signal with at least one spectral component of at least one data output signal, and for emitting a correlation signal which can be processed, such that the at least one signal 30 processing module processes the correlation signal and emits an output-side control

signal for driving an input-side polarization transformer in the controllable polarizing element.

47. A method for optical information transmission using differently  
5 polarized optical signal elements, the method comprising the steps of:

emitting at least one of the optical signal elements via an output side of a controllable polarizing element;

detecting any interference which occurs between the optical signal elements;

10 forming at least one control signal from the detection via at least one signal processing module; and

using the at least one control signal to control the controllable polarizing element.

15 48. A method for optical information transmission as claimed in claim 47, the method further comprising the steps of:

supplying at least one input-side control signal for a regulator to an input of the regulator; and

20 emitting at least one output-side control signal from the regulator and supplying the at least one output-side control signal to the controllable polarizing element.

25 49. A method for optical information transmission as claimed in claim 47, wherein the controllable polarizing element is a fixed polarizing element with a controllable polarization transformer following it.

50. A method for optical information transmission as claimed in claim 49, wherein the controllable polarizing transformer is suitable for PMD compensation and has a downstream output-side polarization transformer.

51. A method for optical information transmission as claimed in claim 48, the method further comprising the step of producing differential phase modulation between the optical signal elements.

5 52. A method for optical information transmission as claimed in claim 51, wherein the differential phase modulation is produced at a start of information transmission.

10 53. A method for optical information transmission as claimed in claim 52, wherein the differential phase modulation is effected such that the input-side control signal is formed at least approximately independently of any steady-state difference phase angle between the optical signal elements.

15 54. A method for optical information transmission as claimed in claim 51, the method further comprising the step of producing frequency modulation for a transmission laser, the frequency modulation producing the differential phase modulation between the optical signal elements based on a magnitude of any delay time difference between a splitting of an optical signal from the transmission laser in a transmission-end power splitter in combination with orthogonal polarizations 20 of the optical signal elements formed in this way.

25 55. A method for optical information transmission as claimed in claim 48, wherein the controllable polarizing element, which emits at least one signal component, is followed by at least one photodetector for each signal component, the at least one photodetector producing a detected signal in which the interference 20 is manifested.

30 56. A method for optical information transmission as claimed in claim 55, the method further comprising the step of passing at least one spectral signal element of at least one signal, which can be processed and is produced from the detected signal, by a filter.

57. A method for optical information transmission as claimed in claim 55, the method further comprising the step of supplying the input-side control signal at least partially to a detector which forms the input-side control signal such that it is at least approximately one of a linear function and a square root function of at least one second-order moment of at least one spectral signal element.

58. A method for optical information transmission as claimed in claim 57, the method further comprising the step of producing, by the detector, a second-order moment, in mixed form, from two different spectral signal elements.

59. A method for optical information transmission as claimed in claim  
57, the method further comprising the step of producing, by the detector, a second-  
order moment of a spectral component, the second-order moment being a measure  
15 of power of the spectral component.

60. A method for optical information transmission as claimed in claim  
56, wherein a Fourier coefficient of the at least one signal is used as the spectral  
signal element of the detected signal with delay time compensation being effected  
before formation of second moments in mixed form.

61. A method for optical information transmission as claimed in claim  
56, wherein the detected signal, via the signal processing module, emits an output-  
side control signal for driving an output-side polarization transformer in the  
controllable polarizing element.

62. A method for optical information transmission as claimed in claim 56, the method further comprising the steps of:

correlating the detected signal via a correlating element in the at least one signal processing module, with at least one spectral component of at least one data output signal;

processing the correlation signal, which is produced during the correlation process, by the at least one signal processing module; and

driving an input-side polarization transformer in the controllable polarizing element via an output-side control signal which is produced during the processing.

5

**REMARKS**

The present amendment makes editorial changes and corrects typographical errors in the specification, which includes the Abstract, in order to conform the specification to the requirements of United States Patent Practice. No new matter is added thereby.

10

Attached hereto is a marked-up version of the changes made to the specification and claims by the current amendment. The attached page is captioned "**Versions with Markings to Show Changes Made.**"

15

In addition, the present amendment cancels original claims 1-31 in favor of new claims 32-62. Claims 32-62 have been presented solely because the revisions by crossing out underlining which would have been necessary in claims 1-31 in order to present those claims in accordance with preferred United States Patent Practice would have been too extensive, and thus would have been too burdensome. The present amendment is intended for clarification purposes only and not for substantial reasons related to patentability pursuant to 35 U.S.C. §§101, 20 102, 103 or 112. Indeed, the cancellation of claims 1-31 does not constitute an intent on the part of the Applicants to surrender any of the subject matter of claims 1-31.

25

Early consideration on the merits is respectfully requested.

Respectfully submitted,

30

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**VERSION WITH MARKINGS TO SHOW CHANGES MADE****In the Specification:****SPECIFICATION****TITLE OF THE INVENTION**5   **Description****SYSTEM AND METHOD FOR OPTICAL INFORMATION TRANSMISSION**

The invention relates to an arrangement and to an associated method for optical information transmission, as claimed in the precharacterizing clause of the independent patent claims 1 and 16.

10

**BACKGROUND OF THE INVENTION**

Polarization multiplexing, ~~an arrangement a system~~ and a method for optical information transmission ~~by means of via~~ differently polarized optical signal elements, are used to increase the capacity of an optical transmission system. The Proceedings of the European Conference on Optical Communications 1993, Montreux, Switzerland, pages 401-404, Lecture WeP9.3, F. Heismann et al., "Automatic Polarization Demultiplexer for Polarization-Multiplexed Transmission Systems" describe an optical polarization-multiplexed transmission system. A major disadvantage of this configuration is that a receiver-end polarization transformer is controlled such that the two polarization-multiplexed channels are split between the two outputs of a downstream polarization beam splitter. This is done by forming a correlation signal of the recovered clock with the received signal, and ~~by through~~ maximizing this by adjustment of the polarization transformer.

The procedure according to the prior art has a number of disadvantages:  
 Firstly First, the correlation product disappears when averaged over time when a pure AC-voltage-coupled pseudo-sequence is applied, ~~and this makes thus making~~ the control process difficult or impossible.

Furthermore, different bit rates had to be chosen in order to distinguish between the two polarization-multiplexed channels, ~~and this which~~ is not feasible in practice. Furthermore, significantly different optical wavelengths had to be chosen ~~and this is, which~~ likewise is unacceptable in practice.

One object of the present invention is, thus, to specify an arrangement a system and an associated method for optical information transmission, which avoid the disadvantages of the prior art.

This object is achieved by an arrangement as specified in claim 1, and by a  
5 method as specified in patent claim 16.

Advantageous developments are specified in the dependent claims.

#### SUMMARY OF THE INVENTION

The A solution to the problem is to detect any interference which occurs in the two optical, differently polarized polarization-multiplexed signals in a signal  
10 processing module, and to use this to control a controllable polarizing element. This is done by conditioning this interference at the transmission end; that is to say, randomizing it. Corresponding spectral signal elements are minimized by a polarization regulator, so that crosstalk in polarization multiplexing is minimized and, at the same time, the useful signals are at least approximately maximized. All  
15 the disadvantages that have been mentioned with the prior art are in this way avoided.

In one exemplary embodiment of the present invention, the polarization-multiplexed signal is produced at the transmission end from a laser signal, which is first of all split between two signal paths, where it is and then, in each case,  
20 separately intensity-modulated. These signal paths are then combined in a polarization beam splitter, with orthogonal polarizations, with the frequency of the laser being modulated at the same time. Any delay time difference between these paths means that the frequency modulation results in differential phase modulation between the multiplexed signals.

At the receiver end, the signal is split by means of via a coupler between  
25 two receiver paths. Input-side polarization control is carried out in each receiver path, followed by a polarizer for suppressing the respectively undesirable polarization-multiplexed channel, and by a conventional photoreceiver in each case having a photodiode; and, finally, electrical data signal regenerators connected  
30 downstream from the photodiodes. Spectral signal elements are in each case detected by means of via a filter. These spectral signal elements disappear only

when one of the multiplexed signals is completely suppressed by the polarizer. This results in a simple and, at the same time, highly effective control criterion for setting the respective polarization transformer. In this case, each of the regenerators receives and regenerates only one polarization-multiplexed channel, 5 which corresponds to the desired receiver-end separation of the signals. In one development embodiment, correlation is carried out, before reaching the filter, preferably with the time derivative of the recovered data signal from the respective other channel. This results in a highly accurate control criterion in order to compensate for polarization mode dispersion.

10 Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

~~The invention will be explained in more detail with reference to exemplary embodiments.~~

15 In the figures:

#### BRIEF DESCRIPTION OF THE FIGURES

Figure 1 shows a polarization-multiplexed transmitter with only one laser;

Figure 2 shows a polarization-multiplexed transmitter with two lasers;

Figure 3 shows a receiver according to the present invention;

20 Figure 4 shows a separator/detector;

Figure 5 shows a variant of a part of the receiver from Figure 3;

Figure 6 shows a vector diagram of linear polarization states;

Figure 7 shows an embodiment variant of a separator/ detector;

Figure 8 shows an embodiment variant of a filter unit;

25 Figure 9 shows a further embodiment variant of a filter unit;

Figure 10 shows a further receiver according to the present invention;

Figure 11 shows a variant of a part of the receiver from Figure 10;

Figure 12 shows a correlating element;

Figure 13 shows one advantageous refinement of the correlating element;

30 and,

Figure 14 shows a further correlating element.

## DETAILED DESCRIPTION OF THE INVENTION

In a transmission arrangement as shown in Figure 1, the output signal from a transmission laser LA is split between two optical waveguides, with approximately the same power levels, ~~by means of~~ via a transmission-end power splitter PMC. Any optical and/or electrical amplifiers which may be required are omitted here and in the following figures, for the sake of clarity. The transmission-end power splitter PMC may be, for example, a polarization-maintaining fiber coupler. The signals obtained in this way are passed through a respective modulator MO1, MO2, which is preferably in the form of an intensity modulator or else, for example, a phase modulator, and where transmission-end modulation signals SDD1 and SDD2, respectively, are applied, thus producing optical signal elements OS1, OS2. These are modulated. OS1 is a first optical signal element, and OS2 is a second optical signal element. These are combined, preferably with orthogonal polarizations, ~~by means of~~ via a transmission-end polarization beam splitter PBSS. A simple optional directional coupler ~~can also~~ can be used instead of the transmission-end polarization beam splitter PBSS.

Polarization-maintaining optical waveguides, for example, can likewise be provided for the connections between the modulators MO1, MO2 and the transmission-end polarization beam splitter PBSS, with one of these optical waveguides being twisted through 90°. As an alternative to this, a mode converter can be provided in one of these connections.

In order to achieve the desired coherence between the optical signal elements, OS1, OS2 after combination, differential phase modulation DPM is provided between these two optical signal elements OS1, OS2, and is produced by a phase-difference-modulating ~~means~~ device. First phase-difference-modulating ~~means~~ devices PDM1, PDM2, PDM12, PDM21, which can be used alternatively or additively, are angle modulators PHMO1, PHMO2 for one of the optical signals, OS1, OS2, or differential angle modulators PHMO12, PHMO21. In this case, the word differential ~~means~~ that refers to the angle modulation takes taking place between the polarized optical signal elements OS1, OS2, which are ideally orthogonal to one another. The frequency shift which may be produced in this case

result results in a frequency difference FD in the output optical waveguide. Frequency shifters, including differential frequency shifters, which are suitable for use as this the first phase-difference-modulating means devices PDM1, PDM2, PDM12, PDM21 may operate, in particular, acoustooptically acousto-optically, or 5 electrooptically electro-optically, and preferably with full mode conversion, in the case of the phase-difference-modulating means devices PDM1, PDM2, PDM12, which is not used for power splitting at the same time. A transmission-end power splitter PMC ~~can also~~ can be used as the phase-difference-modulating means device PDM21; for example, in the form of an acoustooptical acusto-optical mode 10 converter which operates as a frequency shifter and with half power conversion, and this. This is followed by a polarization beam splitter. In a further exemplary embodiment of a polarization-multiplexed transmitter, the transmission laser LA has an optical frequency modulation signal FMS applied to it, ~~with this being~~ which is produced from a further phase-difference-modulating means device PDM0. By 15 way of example, sinusoidal optical frequency modulation FM with a frequency shift of a few hundred MHz has scarcely any effect on the transmission bandwidth of a 10 Gb/s transmitter. If the magnitude of the delay time difference  $|DT1-DT2|$  between the optical delay times DT1, DT2 of the optical signal elements OS1, OS2 which pass through the modulators MO1, MO2 between the transmission-end 20 power splitter PMC and the transmission-end polarization beam splitter PBSS is chosen not to be zero, the frequency modulation is converted to the desired differential phase modulation DPM of the optical signal elements OS1, OS2 downstream from the transmission end-polarization beam splitter PBSS. This has a spectrum which depends on that of the optical frequency modulation FM.

25 In the simplest case, the external optical frequency modulation FM may even be dispensed with, by making use, instead of this, of the natural frequency fluctuations from the transmission laser LA, its line width. These frequency fluctuations also lead, via the magnitude of the delay time difference  $|DT1-DT2|$  between the optical delay times DT1, DT2, to differential phase modulation, DPM 30 between the optical signal elements, OS1, OS2.

Furthermore, differential phase modulation DPM is used between the optical signal elements OS1 and OS2 even when, as an alternative to signal 1, a transmission arrangement as shown in Figure 2 is used, with two optical transmitters TX1, TX2. The optical transmitters TX1, TX2 transmit the 5 orthogonal-polarized optical signal elements OS1, OS2, which are combined in a transmission-end polarization beam splitter PBSS. In this case, the optical transmitters TX1, TX2 interact with the transmission-end polarization beam splitter PBSS as a further phase-difference-modulating means device PDML. The differential phase modulation DPM produced in this way is added to form a steady- 10 state difference phase angle EPS, which occurs at a specific time between the optical signal elements. The optical transmitters TX1, TX2 are modulated with transmission-end modulation signals SDD1 for the optical transmitter TX1 and SDD2 for the optical transmitter TX2.

The aim of the transmission arrangements shown in Figure 1 and Figure 2, 15 is in each case, to randomize the interference phase angle; that is to say, for example, if there is a frequency difference FD between the optical signal elements OS1, OS2 the cosine function and the sine function of the differential phase modulation DPM between the optical signals OS1 and OS2 always have a mean value of zero, so that input-side control signals L1, L2, L12, which are obtained in 20 a way which will be described later, are independent of the steady-state difference phase angle EPS.

Figure 2 also shows the principle of one design of a transmission system using polarization multiplexing. Once the optical signal elements OS1, OS2 have been combined by the transmission-end polarization beam splitter PBSS, the 25 signals can then be transmitted via an optical waveguide LWL to a receiver RX with an input EI. Since the optical waveguide LWL generally does not maintain the polarization, this makes it difficult to separate the two optical signal elements OS1, OS2 once again.

According to Figure 3, the receiver RX comprises includes, for example, a 30 separator/detector SD and downstream receiver electronics.

Figure 4 shows a separator/detector SD for polarization multiplexing. The received optical signal elements are passed from the input EI to a controllable polarizing element SUB. This contains a controllable polarization transformer PT, which is preferably designed to be endless, and receives at least one first output-side control signal ST1, and preferably a second output-side control signal ST2, as well. Both the first output-side control signal ST1 and the second output-side control signal ST2 may consist of one or more signals. A fixed polarizing element EPBS is fitted at the output of the polarization transformer PT and may be in the form of a polarization beam splitter which produces first and second signal components OUT1, OUT2 at its outputs. Ideally, the signal components OUT1, OUT2 should be the orthogonal-polarized optical signal elements OS1 and OS2, respectively; however, this is true only if the controllable polarization transformer PT is adjusted in a suitable manner. This contains a first input-side polarization transformer PMDC, which is designed to be suitable for PMD compensation and is referred to as a PMD compensator, and is controlled by output-side control signals STW1, STW2, which are designed to control it, and contains an output-side polarization transformer SPT, which follows it in the propagation direction of the optical signals OS1, OS2 and is controlled by control signals ST1, ST2, which are designed to control it. When, on the other hand, the controllable polarization transformer PT is not set optimally, crosstalk results due to the respectively undesired optical signal element OS2 or OS1. One idea of the present invention is to detect the interference INT1 and INT2 which respectively occurs in this case in the two optical signal elements OS1, OS2. This interference INT1 and INT2, respectively, occurs in these signal components, OUT1 and OUT2, respectively, in this case by virtue of the optical field strength or the optical power.

The respective signal components OUT1 and OUT2 are detected in respective photodetectors PD11 and PD21, which produce a first detected signal ED1 and a second detected signal ED2. These, in turn, contain the respective interference INT1 and INT2, but in this case by virtue of the photocurrents of the respective photodetectors PD11 and PD21.

- The input-side polarization transformer PMDC, that is to say the PMD compensator PMDC, may be designed, for example, as described in German Patent Applications 19841755.1 and 19830990.2. A version with an at least approximately frequency-independent controllable polarization transformer is likewise of interest, which is followed by a highly frequency-dependent, fixed polarization transformer which, for example, has only first-order polarization mode dispersion. The latter may be formed from a piece of polarization-maintaining fiber with a differential group delay time between two modes. Arrangements such as these are known from IEEE J. Lightwave Technology, 17(1999)9, pages 1602-1616, and the references quoted there. The controllable polarizing element SUB, or parts of it, in particular the controllable polarization transformer PT, may be integrated on a substrate which is composed, for example, of lithium niobate. Instead of the integrated design, the input-side polarization transformer PMDC could also, ~~for example~~, be omitted, with the output-side polarization transformer SPT and the fixed polarizing element EPBS, which is in the form of a polarization beam splitter, being designed as described in the Proceedings of the European Conference on Optical Communications 1993, Montreux, Switzerland, pages 401-404, Lecture WeP9.3. Embodiments according to the subject matters described in German Patent Applications 19858148.3 and 19919576.5 are also possible.
- The detected signals ED1, ED2 are preferably passed to digital receivers D1, D2, as shown in Figure 3. These may contain decision makers and clock recovery units and may emit data output signals DD1, DD2 which, ideally, are logically identical to the transmission-ended modulation signals SDD1 and SDD2, respectively.
- The detected signals ED1, ED2 are passed to a signal processing module DR. In principle, instead of this, the signal components OUT1, OUT2 leaving the controllable polarizing element SUB ~~can also~~ can be passed directly to this signal processing module DR; it. It should then be designed to process these signal components OUT1, OUT2, and the photodetectors PD11, PD21 may be omitted.
- This signal processing module DR detects any interference INT1, INT2 which occurs between the optical signal elements OS1, OS2, and ~~may also~~ may

contain regulators RG1, RG2. Signals EDV1, EDV2 which are in the form of detector signals ED1, ED2 and can be processed are processed for this purpose in the signal processing module DR. This emits an output-side control signal ST1, ST2, which drives the output-side polarization transformer SPT1, SPT2. These 5 signals EDV1, EDV2, which can be processed, are passed to respective filters LED1 and LED2 for this purpose. In order to keep the complexity low, it is, for example, possible to measure the current at that electrode of a photodiode at which the data signal is not tapped off. This results in the advantage that the data signals are not corrupted, and that the desired filtering is at least partially carried out at this 10 stage by the capacitive blocking to ground produced at the other electrode of the photodiode. In this case, detected signals ED1, ED2 each ~~comprise~~ include a broadband data signal on one line, and a low-frequency signal on another line. The former is processed further in the digital receiver D1 or D2, respectively, while the latter is supplied to the respective filter LED1 or LED2.

15 As an alternative to this, the broadband data signal on one line and the low-frequency data signal on another line may each originate from two different photodiodes which, together with in each case one upstream further optical beam splitter, form the respective photodetector PD11 or PD21.

The filters LED1, LED2 are preferably designed as bandpass filters, with a 20 low frequency in comparison to the symbol rate, and thus select spectral signal elements FIO1, FIO2 in whose frequency bands interference INT1, INT2 between the optical signal elements OS1 and OS2 occurs due to the specific configuration of the transmission apparatus, as shown in Figures 1 or 2, in the controllable polarizing element SUB. In the case of optical frequency modulation FM, this is, 25 in each case, the modulation frequency MO, which is ~~in general~~ not identical to the frequency modulation shift  $\neq$  of, for example, 1 MHz, or the other modulation frequencies in the range from about 0.1 Hz to 1 GHz are at least, in principle, suitable. Multiples  $n^*MO$  of the modulation frequency where n is an integer ~~may~~ also may be evaluated on their own or together with it. The filters LED1, LED2 30 are preferably in the form of bandpass filters. It is likewise possible for them to be in the form of low-pass filters, ~~which~~ with the DC component being passed

through. In the case of an a periodic frequency modulation signal FMS or a frequency difference FD, which fluctuates severely through the line widths of the optical transmitters TX1, TX2, between the optical signal elements OS1, OS2, the filters LED1, LED2 ~~can~~ preferably can pass the spectral maximum of the 5 interference INT1, INT2 in the detected signals ED1, ED2.

The selected spectral signal elements FIO1, FIO2 at the outputs of the filters LED1, LED2 are passed to detectors DET1 and DET2, respectively, which, possibly after low-pass filtering in the low-pass filters LPF1, LPF2, produce input-side control signals L1, L2. These detectors DET1, DET2 may be in the form of 10 root mean square value detectors, or power detectors. By definition, in the case of power detectors, the second-order moment SOMD1, SOMD2 of the corresponding spectral signal element FIO1, FIO2 is evaluated. The input-side control signal L1, L2 is then a linear function F of this second-order moment SOMD1, SOMD2. In the case of root means square value detectors, the input-side control signal L1, L2 15 is a square-root function F of this second-order moment SOMD1, SOMD2 of this spectral signal element FIO1, FIO2. Peak value detectors or similar devices ~~may possibly also~~ may be used, especially if the spectral signal element FIO1, FIO2 is essentially at a signal frequency whose peak value, ~~in this case as well~~, is at least approximately a square root function F of the power; that is to say, of this second-order moment SOMD1, SOMD2 of this spectral signal element FIO1, FIO2. The input-side control signals L1, L2 are passed to regulators RG1, RG2, whose output signals are used as output-side control signals SD1, SD2 for driving the controllable polarizing element SUB in the separator/detector SD; in this case, the polarization transformer PT contained in it. The regulators RG1, RG2 are designed 20 such that the input-side control signals L1, L2 assume minimum magnitudes; that is to say, minimum interference INT1, INT2 is indicated between the optical signal elements OS1 and OS2. This ensures optimum receiver operation.

The signal processing module DR, according to the present invention and as already described, of the receiver RX in Figure 3 ~~can~~ also can be embodied by 30 ~~means of via~~ a further variant of the present invention illustrated in Figure 5. This is possible in situations in which a separator/detector SD with a controllable

polarizing element SUB is provided, which on the output side emits signal components OUT1, OUT2 which correspond at least approximately to orthogonal components of the signal elements OS1, OS2 passed to it; that is to say, for example, which has a controllable polarization transformer PT followed by a

5 polarization beam splitter as a fixed polarizing element EPBS, as shown in Figure 4. Since the interference INT1, INT2 and, if the same frequency bands are chosen, the spectral signal elements FIO1, FIO2 as well are then always in antiphase in the two receiver paths (assuming that the electrical signal polarities of the receiver paths are the same) the difference between the first and second

10 signals, EDV1, EDV2, which are in the form of first and second detected signals ED1, ED2, respectively, and can be processed, is processed respectively as further detected signals ED1-ED2 and, at the same time, as a further signal EDV12 which can be processed, in a first subtractor SUBED12 for situations such as this, in Figure 5. This is supplied to a filter LED12, which is designed in the same way as

15 the filters LED1, LED2 and allows a further spectral signal element FIO12 to pass. This is supplied to a detector DET12, which is designed in the same way as the detectors DET1, DET2 and uses the signal element to produce a further input-side control signal L12 which, for example, is identical to the second-order moment SOMD12 of this further spectral signal element FIO12. This may be followed by a

20 low-pass filter LPF12, designed in the same way as the low-pass filters LPF1, LPF2. A regulator RG produces output-side control signals ST1 and, possibly ST2. This is designed such that the input-side control signal L12 supplied to it is minimized, so that the interference INT1, INT2 is thus also minimized. In principle, a single further filter LED12 will be sufficient to produce the input signal

25 for the single detector DET12; however, since broadband subtractors SUBED12 are costly, it is generally better to provide filters LED1 and LED2 first of all at the inputs of a correspondingly relatively narrowband first subtractor SUBED12 and, possibly, nevertheless a further filter LED12 at its outputs, which, when cascaded with the respective filter LED1 or LED2, produces the desired

30 spectral form of the difference between the detected signals ED1, ED2.

The regulators RG1, RG2, RG in Figures 3 and 5 preferably operate on the basis of a lock-in method and preferably have integral or proportional-integral control elements. The regulators RG1, RG2, RG also may, possibly, also be omitted, so that one input-side control signal L1, L2, L12 is at the same time used as the output-side control signal ST1, ST2.

Both the input-side control signals L1, L2, L12 and the output-side controls signals ST1, ST2 of the regulators RG1, RG2, RG are control signals L1, L2, L12, ST1, ST2.

If the optical frequency modulation FM is produced by ~~is~~(preferably sinusoidal)~~is~~ direct modulation of a semiconductor laser, the optical signal elements OS1, OS2 have not only the desired differential phase modulation DPM produced by optical frequency modulation FM and having a shift ETA (which in the following text is regarded as the peak shift in radians), but also undesirable amplitude modulation. This is not dependent on the polarization states chosen at the receiver end; and, thus makes, it is harder to set the polarizations in controllable polarizing elements, SUB, SUB1, SUB2;~~is~~ in particular, in controllable polarization transformers PT, PT1, PT2. In cases such as this, it may be worthwhile evaluating multiples n\*OM, for example n = 2, 3, 4, ..., of the modulation frequency OM.

At least in the case of sinusoidal frequency modulation FM, the amplitudes of even ( $n = 0, 2, 4, \dots$ ) and odd ( $n = 1, 3, 5, \dots$ ) multiples  $n \cdot OM$  of the modulation frequency OM, detected at the receiver end, are proportional to the cosine and sine, respectively, of steady-state difference phase angle EPS, which is sensitively dependent on the magnitude of the delay time difference  $|DT_1 - DT_2|$  between the optical delay times DT1, DT2.

25        However, according to the present invention, it is possible to evaluate at least one even multiple of the modulation frequency OM, and at least one odd multiple of the modulation frequency OM, at the same time. Provided the filter or filters LED1, LED2, LED12 are designed in a suitable manner, the respective filter output power is a second-order moment SOMD1, SOMD2, SOMD12, and the input-side control signals L1, L2, L12 is/are thus also proportional to  $\cos^2(\text{EPS}) + \sin^2(\text{EPS}) = 1$ ; that is to say, independent of the steady-state

30

difference phase angle EPS. LOM<sub>n</sub> is assumed to be a power transmission factor for the multiple  $n \cdot OM$ . In a first such example, the modulation frequency OM, corresponding to the Bessel line J<sub>1</sub>, where J<sub>n</sub> is an n-th order Bessel function of the first kind, and twice the modulation frequency 2\*OM, corresponding to the Bessel line J<sub>2</sub>, are passed through filters LED1, LED2, LED12, and the detectors DE1, DET2, DET12 are power detectors or root mean square value detectors. LOM1\*J<sub>1</sub>(ETA)<sup>2</sup> is set to be LOM2\*J<sub>2</sub>(ETA)<sup>2</sup>, and is achieved, at least approximately, for example, by  $|J_1(ETA)| = |J_2(ETA)|$  where ETA = 2.63 and LOM1=LOM2.

The further refinement of the principle of the present invention on which this embodiment is based is that the detected (or even the detectable, provided the detection process is independent of frequency) first power PEVEN or second power PODD, which is measured by detection of only even or only odd multiples of the modulation frequency OM in the input-side control signal L<sub>1</sub>, L<sub>2</sub>, L<sub>12</sub>, has a sum PEVEN+PODD which is independent of the steady-state difference phase angle EPS. It also has the same expected values.

Further exemplary embodiments based on this principle are described below:

It is possible for the modulation shift ETA to be subjected to fluctuations over the course of time; for example, due to aging of the laser. In order, nevertheless, to make it possible to keep the detection process independent of the difference phase angle EPS, to a first approximation, the input-side control signals L<sub>1</sub>, L<sub>2</sub>, L<sub>12</sub> must, to a first approximation, be independent of the modulation shift ETA. This is achieved, for example, ~~by means of~~ via filters LED1, LED2, LED12, which are in the form of bandpass filters and each pass the modulation frequency OM, twice this frequency 2\*OM, and three times this frequency 3\*OM. The power transmission factor values required to do this are at least approximately LOM1=0.72852\*LOM2 and LOM3=1.6036\*LOM2, and ETA is chosen to be at least approximately 3.0542.

As mentioned above, detection using the single modulation frequency OM may result in problems, so that it may be better to carry out the detection process at

2\*OM, 3\*OM, 4\*OM instead. The power transmission function values required in this case are at least approximately LOM2=0.64066\*LOM3 and LOM4=1.3205\*LOM3 and ETA is chosen to be at least approximately 4.2011. Those power transmission factors which have not been mentioned, that is to say in the present example LOM0, LOM1, LOM5, LOM6, LOM7, ... for frequencies 0, OM, 5\*OM, 7\*OM, ..., are in each case assumed to be at least approximately equal to zero.

If amplitude modulation also occurs in addition to the optical frequency modulation FM, the required power transmission factors LOMn ( $n = 0, 1, 2, \dots$ ) 10 may differ from the values quoted above, to be precise with the difference increasing with the level of amplitude modulation.

It can be difficult to design bandpass filters such as these. In a further refinement embodiment of the present invention, a number of filters, or else individual filters LEDOMn, which are preferably in the form of bandpass filters, 15 can be provided for frequencies  $n*OM$ , since these signals are mathematically orthogonal at the frequencies  $n*OM$ , so that their individual power levels can be added directly, without any cross-power terms. These filters LEDOMn each have a detector DETOMn connected to them, preferably in the form of a power measurement device. One embodiment such as this of the elements illustrated in 20 Figures 3 and 5, namely filters LED1, LED2, LED12, detectors DET1, DET2, DET12 and low-pass filters LPF1, LPF2, LPF12, which can be combined to form filter units FE1, FE2, FE12, is shown in Figure 8. Here, in a corresponding way to that in the last exemplary embodiment,  $n = 2, 3, 4$ , but it is likewise possible to select different values of  $n$ . The filter unit FE12, which is implemented as an 25 alternative in Figure 8, may also may include the subtractor unit SE in which case linear function blocks can be shifted or split in accordance with the commutative or distributive law.

The splitting is carried out on filters LEDOMn where  $n$  is an integer. The output signals from these filters LEDOMn are spectral signal elements FIOOMn 30 where  $n$  is an integer, and are essentially composed of spectral components at the frequencies  $n*OM$ . These spectral signal elements FIOOMn, where  $n$  is an integer,

are passed to detectors DETOM<sub>n</sub>, where n is an integer. The power transmission factors LOM<sub>n</sub> are each obtained by multiplication of the power transmission factor of a filter LEDOM<sub>n</sub> by that of a weight G<sub>n</sub>, which is part of the associated detector DETOM<sub>n</sub>, or is downstream from it. The weight G<sub>n</sub> may be provided from a  
5 potentiometer. At the latest after the weighting by the weight G<sub>n</sub>, a second-order moment SOM<sub>n</sub> is obtained in each case, where n is an integer, namely the power of the spectral signal element FIOOM<sub>n</sub>. This second-order moment SOM<sub>n</sub> is added to the respective power transmission factor LOM<sub>n</sub> in an adder ADD. In this case,  
10 according to the present invention, a first power PEVEN of at least one spectral component where n is even, and a second power PODD of at least one spectral component where n is odd, are added. The desired input-side control signal L1, L2 or L12 is produced at the output of the adder ADD and, possibly, after passing through a low-pass filter LPF1, LPF2, LPF12, in a corresponding way to the exemplary embodiments of filter units FE1, FE2 or FE12 in Figures 3 or 5, which,  
15 according to the present invention, is once again independent of the steady-state difference phase angle EPS and, to a first approximation, is independent of the modulation shift ETA, since it is a constant sum PEVEN+PODD of the first power PEVEN of even spectral components, and of the second power PODD of odd spectral components.

20 The input-side control signal L1, L2, L12 is a function F of the second-order moment SOM<sub>n</sub> of these spectral signal elements FIOOM<sub>n</sub>, which is linear, namely, the weighted sum of the individual power levels of these spectral signal elements FIOOM<sub>n</sub>. Detection and addition may also may be interchanged. In this case, the detectors DETOM<sub>n</sub> and possibly weights G<sub>n</sub> in Figure 8 must be replaced  
25 by through-links while a detector DET1, DET2, DET12 which was not required until now in Figure 8 and could, therefore, could be replaced by a through-link until now and which is a power or a root mean square value detector, is provided downstream from the adder ADD.

In practice, it is advantageous for the filter units FE1, FE2, FE12 according  
30 to Figure 8 or parts of Figures 3 and 5 to be provided by digital signal processing

using a microprocessor. This microprocessor ~~may also~~ provide the regulators RG, RG1, RG, or parts of them.

Further variations of the principle of the present invention are feasible by providing different time profiles for differential phase modulation, DPM between the two optical signal elements OS1, OS2. Such time profiles are preferably designed such that an input-side control signal L1, L2, L12 is as independent as possible of the amplitude of the differential phase modulation DPM or of optical frequency modulation FM, which produces the phase modulation, in a transmission laser LA.

In practice, sinusoidal current modulation as a frequency modulation signal FMS for a transmission laser LA in any case results in non-sinusoidal frequency modulation FM and, hence ~~also~~, in non-sinusoidal differential phase modulation DBM between the optical signal elements OS1, OS2. There is thus ~~also~~ no pure Bessel spectrum in the detected signals ED1, ED2; in particular, the modulation frequency OM is generally strongly represented. In order, in contrast to the situation described above, for there to be no need to change their higher harmonics  $n \cdot OM$ , for example up to  $n = 4$ , suitable second-order moments SOM $n$  of the spectral signal elements DETOM $n$  and/or possibly mixed second-order moments SOM $m,n$ , where m, n are integers, may be defined between them.

Figure 9 once again shows a filter unit FE1, FE2, FE12, to which a detected signal ED1, ED2, ED1-ED2 is passed. A filter LED with a downstream detector DET is provided, which is in the form of a microprocessor with an input-side analogue/digital converter. This detector DET is used to calculate the Fourier components relating to the modulation frequency OM and twice this frequency  $2 \cdot OM$ , as spectral signal elements FIOOM1, FIOOM2, which can be carried out as filtering in filters LEDOM1, LEDOM2, which are in the form bandpass filters, within a filter LED. Owing to the formation of the mixed second-order moment SOM12, the two spectral signal elements FIOOM1, FIOOM2 ~~have~~ preferably already ~~had~~ removed from them their delay time, which results from the fact that the formation of the Fourier coefficients does not necessarily coincide in time with the oscillation of the frequency modulation FM. If, for example, a Fourier

component FIOOM1 of the spectral signal element at the modulation frequency OM has a complex phase vector, then all the determined Fourier components FIOOM1, FIOOM2, ... FIOOMn are multiplied by the 1st, 2nd, .. n-th power of the complex conjugate of this phase vector, in accordance with the shift rule for Fourier transformation. A weighted sum of the second-order moment SOM1, SOM2, SOM12 of these two spectral signal elements FIOOM1, FIOOM2 and of the mixed second-order moment is formed between these two spectral signal elements FIOOM1, FIOOM2, and is used as the input-side control signal L1, L2, L12. The weights used in this case are at the same time the corresponding power transmission factors LOM1, SOM2, LOM12 of these second-order moments SOM1, SOM2, SOM12. They are chosen to produce an input-side control signal L1, L2, L12 which is independent of the steady-state difference phase angle EPS. This can be done by inversion of a 3x3 matrix.

If a pure Bessel spectrum is present, the power transmission factor LOM12 of the mixed second-order moment SOM12 is chosen to be equal to zero and, as mentioned above,  $LOM1 \cdot J1(\text{ETA})^2$  is set to be  $LOM2 \cdot J2(\text{ETA})^2$ , as is achieved, at least approximately, for example, ~~by means of via~~  $|J1(\text{ETA})| = |J2(\text{ETA})|$  where  $\text{ETA} = 2.63$  and  $LOM1 = LOM2$ . In practice, in contrast, the distortion which occurs in the optical frequency modulation FM generally ~~means~~ requires that a power transmission factor LOM12 other than zero is be required for the mixed second-order moment SOM12 and this may even be negative. As or complex. As an extension to this exemplary embodiment, in addition to ~~said the~~ spectral signal elements FIOOM1, FIOOM2, further spectral signal elements FIOOMn, second-order moments SOMn relating to them and all the possible mixed second-order moments SOMmn, where m, n are integers, may be formed between, in each case, one spectral signal element FIOOMm and another spectral signal element FIOOMn and, weighted with weights, may be added to form an input-side control signal L1, L2, L12, so that this results in an input-side control signal L1, L2, L12 which is independent of the steady-state difference phase angle EPS. Optical weights, which also take account of the signal-to-noise ratios in the individual spectral signal elements FIOOMn, can be determined here, for example,

by linear programming using the simplex method. This relates, in particular, to the spectral signal element FIOOM3 at three times 3\*OM the modulation frequency OM as well as to the spectral signal element FIOOM0, which represents a DC signal and may have a constant offset, at zero times 0\*OM the modulation frequency OM.

In order to obtain an uncorrupted input-side control signal L1, L2, L12 despite any parasitic amplitude modulation which may be present, those essentially constant components of the spectral signal elements FIOOM1 and, possibly, FIOOM2, FIOOM3, ..., which are caused by this amplitude modulation can be subtracted before further processing of these spectral signal elements FIOOM1, and, possibly, FIOOM1, FIOOM3, ... .

Reduced orthogonality in the received optical signal elements OS1, OS2 can occur by non-ideal multiplexing at the transmission end, in the transmission-end polarization beam splitter PBSS, or as a result of polarization-dependent attenuation or amplification in the optical waveguide LWL. As shown in Figure 6 and Figure 7, it is advantageous in cases such as these to provide a further controllable polarizing element SUB1, SUB2 in each case, with power splitting being provided ~~by means of via~~ a receiver-end power splitter TE, which may be part of the further controllable polarizing elements SUB1, SUB2, or may be upstream of them. In Figure 7, these further controllable polarizing elements SUB1, SUB2 are further controllable polarization transformers PT1, PT2. These contain in each case one further input-side polarization transformer PMDC1, PMDC2, which is designed to be suitable for PMD compensation, and is referred to as PMD compensator, which is controlled by, in each case, at least one output-side control signal STW1, STW2, which is designed to control it, and in each case one output-side polarization transformer SPT1, SPT2, which is downstream from it in the propagation direction of the optical signals OS1, OS2 and is controlled by in each case at least one control signal ST1, ST2, which is designed to control it. Instead of or in addition to these further input-side polarization transformers PMDC1, PMDC2, which are designed to be suitable for PMD compensation, it is possible, upstream of the receiver-end power splitter TE, to use the first input-side

polarization transformer PMDC, which is designed to be suitable for PMD compensation. These further controllable polarization transformers PT1, PT2 are followed by a respective downstream further, first and second fixed polarizing element EPBS1, EPBS2, which may be in the form of polarization beam splitters or polarizers. The further controllable polarizing elements SUB1, SUB2, or parts of them, may once again be integrated on the substrates. The input-side polarization transformers PMDC, PMDC1, PMDC2 ~~may initially~~ may not be present and may be replaced by through-links, so that the input EI of the separator/detector SD is connected directly to the receiver-end power splitter TE. The polarization matching processes which are achieved according to the present invention by the exemplary embodiment shown in Figure 7 are sketched in Figure 6, for linear polarization situations. The received optical signal elements OS1, OS2 are, in this example, not polarized orthogonally with respect to one another. The first signal component OUT1, with which is transmitted by the first fixed polarizing element EPBS1, is, however, in this case orthogonal to the second optical signal element OS2, and the second signal component OUT2, which is transmitted by the second fixed polarizing element EPBS2, is in this case orthogonal to the first optical signal element OS1. In order to achieve the settings shown in Figure 6, it is preferable to use the refinement of the signal processing module DR shown in Figure 3.

Depending on the way in which the differential phase modulation DPM is produced between optical signal elements OS1 and OS2, the signal processing module DR and, in particular, the filters LED1, LED2, LED12 and the detectors DET1, DET2, DET12 may be varied to an even greater extent. Yet, when the magnitude of the delay time difference between the optical delay times DT1, DT2 is  $|DT1-DT2|$ , the optical frequency modulation FM is not used, and the differential phase modulation DPM is produced by natural frequency fluctuations of the transmission lasers LA, then the filters LED1, LED2 LED12 should be designed such that major parts of the resultant interference spectrum, which generally extends over a number of MHz, are passed through. If, as is shown in Figure 1, angle modulators PHMO1, PHMO2 or a differential angle modulator PHMO12 is or are used, and this or these is or are in the form of frequency shifter

or differential frequency shifter, or if, as is shown in Figure 2, optical transmitters TX1, TX2 at different frequencies are used, then the filters LED1, LED2, LED12 must be matched to the resultant difference frequency FD between the optical signal elements OS1 and OS2. ~~Acousto-optical~~ Acoustooptical and ~~electrooptical~~  
 5 electro-optical components, for example, may be used as frequency shifters or differential frequency shifters. As an alternative to this, phase modulators or a differential phase modulator may be used as angle modulators PHMO1, PHMO2 or as a differential angle modulator PHMO12, and this or these is or are driven so as to produce differential phase modulation DPM, which is at least partially linear as a function of time, and with the time derivative of the differential modulation phase being  $2\pi$  times the frequency difference FD. These are, for example, phase modulators based on the Serrodyne principle, with a sawtooth phase shift.  
 10

If the angle modulators PHMO1, PHMO2 or the differential angle modulator PHMO12 are or is in the form of phase modulators or a differential phase modulator with sinusoidal differential phase modulation DPM, this in contrast results in a Bessel spectrum, as in the case of sinusoidal optical frequency modulation FM, whose detection ~~has already~~ has been considered further above.  
 15

Finally, signals which are used for checking and, possibly, for slow readjustment or deliberate pre-emphasis of the transmission-end polarization orthogonality, can be obtained by measuring the power levels of the detected signals ED1, ED2 or by reading the residual component, which remains despite the stabilization of the polarization transformer PT, of the further regulator input signal L12, which is obtained from the difference between the first detected signal ED1 and the second detected signal ED2. This allows the transmission system to be  
 20 optimized such that, for example, polarization-dependent attenuation in the optical waveguide not only does not lead to any crosstalk, but also does not lead to any adverse affect on one of the optical signal elements OS1, OS2 in comparison to the other.  
 25

In addition, for example by applying further optical frequency modulation,  
 30 or by using natural optical frequency modulation contained in the spectrum of the transmission laser LA, for example at a frequency other than the modulation

frequency OM, or by evaluation of the regulator signals, it is possible to obtain information which, for example, allows adaptive control of the modulation shift ETA or of power transmission factors LOMn.

In an arrangement as shown in Figure 9, it is particularly advantageous to determine the expected values of a number of moments, or of all the moments, SOM1, SOM2, ..., SOMn, SOM12, ... SOMmn that occur in the spectral signal elements FIOOMn where n is an integer. Specifically, this allows the modulation shift ETA to be calculated. The frequency modulation signal FMS, and hence the optical frequency modulation FM can be set on the transmission laser LA by means of via a return channel, so as to achieve an optimum signal-to-noise ratio for the regulator input signal L1, L2, L12 that is obtained. Slow thermal frequency modulation of a transmission laser A that is formed by a semiconductor is suitable, for example, as additional frequency modulation to allow the formation of these expected values.

Overall, the previous exemplary embodiment of the present invention preferably relates to the adjustment of an output-side polarization transformer SPT, SPT1, SPT2, which cannot compensate, or can compensate only to a minor extent, for any polarization mode dispersion which may occur. The following exemplary embodiments of the present invention preferably relate, in contrast, to the adjustment of an input-side polarization transformer PMDC, PMDC1, PMDC2, which is suitable for PMD compensation. The optical complexity is minimized if the control signals for the PMD compensator PMDC in Figure 4 or the PMD compensators PMDC1 and PMDC2 in Figure 7 are derived from the first and second detected signal ED1, ED2. This is done, for example, by simple electrical spectral analysis; attenuation of high-frequency signal components indicates uncompensated PMD, and can be avoided by suitable adjustment of an input-side polarization transformer PMDC, PMDC1, PMDC2.

In one advantageous refinement embodiment of the present invention, the receiver RX as shown in Figure 10, may have a further signal processing module DRW instead of the signal processing module DR or, preferably, in addition to it. On the input side, the further signal processing module receives the detected signals

ED1, ED2 which are passed to a respective first correlation input EIME11, EIME21 of a correlating element ME1, ME2. The data output signal DD2, DD1, which is obtained from the respective other detected signals ED2, ED1, is passed to a respective second correlation input EIME12, EIME22 of the correlating elements  
5 ME1, ME2. A further signal EDW1, EDW2, which is in the form of a correlation signal and can be processed, is produced by a respective output of the correlating element ME1, ME2. These further signals EDW1, EDW2, which can be processed, are passed to further filter units FEW1, FEW2, which are designed in the same way as the abovementioned above-mentioned filter units FE1, FE2, FE12. On the  
10 output side, these filter units FE1, FE2, FE12 emit further input-side control signals, LW1, LW2, which are passed to further regulators, RGW1, RGW2, which are designed in the same way as the abovementioned regulators RG1, RG2. On the output side, these further regulators RGW1, RGW2 emit further control signals, STW1, STW2 for controlling the input-side polarization transformers PMDC1,  
15 PMDC2, PMDC.  
The further signal processing module DRW in the receiver RX in Figure 10 may be in the form of a further variant of the present invention, as shown in Figure 11. This is preferably possible in situations in which there is only one common input-side polarization transformer PMDC. Analogously to Figure 5, an additional  
20 signal EDW12, which is in the form of a correlation signal and can be processed, is produced from the further signals EDW1, EDW2, which are in the form of correlation signals and can be processed, by means of via a further subtractor SUBEDW. This signal EDW12 is passed to a further filter unit FEW12, which may be designed in the same way as the filter units FE1, FE2, FE12, FEW1,  
25 FEW2. On the output side, this emits a further input-side control signal LW12, which is supplied to a further regulator RDW which can be designed in the same way as the regulators RG1, RG2, RG, RG1, RG2 and emits the further output-side control signal STW1, STW2. The correlating elements ME1, ME2 and the further subtractor SUBEDW which is connected to its outputs can be combined to form a  
30 correlating subtraction unit SEW, although this may also may be designed differently.

Figure 14 shows an example of a different embodiment of the correlating subtraction unit SEW. The detected signals ED1, ED2 are subtracted in a further subtractor SUBEDW12, which, in principle, can be designed in the same way as the first subtractor SUBED12 but, owing to the subsequent correlation, should be  
5 designed to have a sufficiently broad bandwidth, so that a further detected signal ED1-ED2 is produced. This is passed to a first input EIME1 of a further correlating element ME12, which can be designed in the same way as the correlating elements ME1, ME2. The data output signals DD2, DD1 are subtracted in an additional subtractor SUBDD21, so that this results resulting in a further data  
10 output signal DD2-DD1, which preferably has three values if the data output signals DD2, DD1 have two values. This further data output signals DD2-DD1 is passed to a second input EIME2 of the further correlating element ME12. At its output, the further correlating element ME12 emits the additional signal EDW12, which is in the form of a correlation signal and can be processed.

15 The design for a correlating element ME1, ME2, ME12 is shown in Figure 12. The detected signal ED1, ED2, ED1-ED2, which contains the interference INT1, INT2, is passed via the first correlation input EIME11, EIME21, EIME1 to a first switching element input EISE1 of a switching element SEE which is preferably in the form of a multiplier. Those components of the interference INT1,  
20 INT2 which are to be added to the polarization mode dispersion are preferably produced at the transitions of adjacent information bits in the transmission-end modulation signals SDD1, SDD2, to be precise with polarities which depend on the direction of these transitions. Thus, in an advantageous refinement of the principle according to the present invention, the received and regenerated data output signal  
25 DD2, DD1, which is obtained from the respective other detected signal ED2, ED1, is first of all passed to a spectral forming element SF, via the second correlation input EIME12, EIME22. In the case of the further correlating element ME12, the further data output signal DD2-DD1 is passed, instead of this, to the corresponding second correlation input EIME2. The spectral forming element SF has a further subtractor SUBME, to whose two inputs the respective data output signal DD2,  
30 DD1, DD2-DD1 is applied directly, or after being delayed by a delay element DEL.

At its output, which is also one output of the spectral forming element SF, this further subtractor SUBME emits a spectrally formed signal DDSF2, DDSF1, DDSF, which is passed to a second switching element input EISE2 of the switching element SEE. The spectral forming element SF in this exemplary embodiment forms, as the spectrally formed signal DDSF2, DDSF1, DDSF at least approximately a time derivative of the respective data output signal DD2, DD1, DD2-DD1; that is to say, this corresponds to high-pass filtering. The delay element DEL may be designed to have a fixed or a variable delay time. A suitable delay time is, for example, a short time, ~~for example of such as~~ one bit period or 5 less of a transmission-end modulation signal SDD1, SDD2, if distortion is intended to be detected ~~by means of via~~ short differential delay times, or longer delay times, which are equivalent to or exceed one, or even a number, of these bit periods, if distortion is intended to be detected ~~by means of via~~ longer differential delay times. Since the respective data output signal DD2, DD1, DD2-DD1 is a digital signal, the 10 delay element DEL ~~may likewise~~ ~~may~~ operate in a digital manner; in particular, preferably in binary form if the data output signal DD2, DD1 is binary. For better signal forming, it may, for example, be in the form of a D-flipflop DFF, which is controlled by one flank of a clock signal CL which is supplied. A chain ~~comprising~~ ~~having~~ a number of D-flipflops is also feasible; in order to extend the delay time of 15 the delay element DEL. In the case of a three-value data output signal DD2-DD1 on the other hand, an ~~analogue~~ ~~analog~~ version of the delay element DEL is preferable; for example, in the form of a delay line. Since the data output signal DD2, DD1, DD2-DD1 which is supplied to the correlating element ME1, ME2, ME12 is obtained from the respective detected signal ED2, ED1, ED1-ED2, ~~this it~~ 20 is generally delayed only by the unavoidable delay time of the digital receiver or receivers D2, D1 and, since it is further delayed in the spectral forming element SF, in the example in Figure 12 by, on average, half the delay time of the delay element DEL, it is normally necessary to carry out a delay time adjustment process between the signals arriving at the first switching element input EISE1 and the second 25 switching element input EISE2 of the switching element SEE. This can be done ~~by means of via~~ a further delay element DDEL, which delays the respective detected 30

signal ED1, ED2, ED1-ED2 or preferably before it is passed onto the switching element SEE. The switching element SEE, and hence the correlating element ME1, ME2, ME12 emits, on the output side, the signal EDW1, EDW2, EDW12, which is in the form of a correlation signal and can be processed.

5 Alternative refinements embodiments of the present invention may, in each case, have a number of correlating elements for the detection of each of those components of the interferences INT1, INT2 which indicates the polarization mode dispersion and/or may be spectral forming elements SF in the form of fixed or variable high-pass, bandpass or low-pass filters.

10 One advantageous practical refinement of the correlating element ME1, ME2, which is particularly suitable when binary data output signals DD2, DD1 are present, is shown in Figure 13. The power supply is provided by a supply voltage U+. The respective detected signal ED1, ED2 is in differential form. After passing through the further delay element DDEL, which, for example, ~~comprises~~ includes two delay lines DDEL1, DDEL2 of equal length, the signal is passed to two differential amplifiers DF1, DF2, which are connected in parallel, with opposite polarities, on the input and output sides. These differential amplifiers DF1, DF2 amplify the respective differential input signal, provided one of two currents I1, I2, which are produced from preferably identical constant current sources, flows 15 through them. However, a first switching transistor TT1 provides a discharge path for the first current I1 when its base is supplied with a data output signal DD2, DD1 ~~/which requires a positive level for this method of operation here/~~ which is obtained from the respective other detected signal ED2, ED1. A second switching transistor TT2 provides a discharge path for the second current I2, when its base is supplied with this data output signal DD2, DD1, which was previously delayed in 20 the delay element DEL and is obtained from the respective other detected signal ED2, ED1 of the first and second detected signals ED1, ED2. As the difference voltage between preferably identical resistors, R1, R2, the further signal EDW1, EDW2, which is in the form of a correlation signal and can be processed, is 25 produced as the differential output voltage from the parallel-connected differential amplifiers DF1, DF2. A capacitor C, which is fitted between the parallel-connected 30

outputs of the differential amplifiers DF1, DF2, is already used as a low-pass filter, which, at least partially, represents the filter LED1, LED2. In Figure 13, the further subtractor SUBME, the switching element SEE and the filter LED1, LED2 which is at least partially formed by the capacitor C cannot be separated from one another, 5 which advantageously leads to reduced complexity, and the capability to process a higher data rate.

The principle of the present invention can be varied by omitting the spectral forming element SF, by the switching element SEE being other than in the form of a multiplier, by it ~~having~~ having at its second input a signal DDSF2, DDSF1, which is not obtained, or is obtained not only, from that data output signal DD2, DD1 which is obtained from the respective other detected signal ED2, ED1, but, for example, is also ~~obtained~~ obtained from that data output signal DD1, DD2 which is obtained from the detected signal ED1, ED2 supplied to the first input of the switching element, and/or at least one detected signal ED1, ED2. Such an example ~~has already~~ has been given by the version of the correlating subtraction unit SEW illustrated in Figure 14.

The example embodiments of the present invention illustrated in Figures 10 to 14 are based; to the extent described so far, on the data output signals DD1, DD2 which are taken from the digital receivers D1, D2 corresponding to the transmission-end modulation signals SDD1, SDD2. However, particularly if the input-side polarization transformers PMDC, PMDC1, PMDC2 are set incorrectly, it is possible for this not to be true; for example, because the detected signals ED1, ED2 do not on the one hand correspond approximately to the transmission-end modulation signals SDD1, SDD2, or because the detected signals ED1, ED2 both each correspond to that transmission-end modulation signal SDD1, SDD2. In order to preclude situations such as this, the further regulator RGW1, RGW2, RGW can vary the further output-side control signals STW1, STW2 when cases such as this occur such that the input-side polarization transformer or transformers PMDC1, PMDC2, PMDC is or are changed to different states. This can also result in the necessity to, at the same time, vary the output-side control signals, ST1, ST2 emitted from the regulators RG1, RG2, RG. This is continued in a systematic or

random manner until at least one, but preferably both, of the data output signals DD1, DD2 obtained from the digital receivers D1, D2 corresponds or correspond at least approximately to the respective transmission-end modulation signals, SDD1, SDD2. Alternatively, or in addition to this, further methods can be used for  
5 determining distortion, referred to as PMD distortion, caused by polarization mode dispersion. Distortion analyzers DANA1, DANA2, to which the detected signals ED1, ED2 are supplied, are provided for this purpose in Figure 10. The distortion analyzers DANA1, DANA2 determine, for example ~~by means of~~ via one or more high-pass or bandpass filters, spectral components of the detected signals, which  
10 ~~can also~~ can be added up; and ~~can be~~ passed to the further regulator RGW1, RGW2, RGW as, in each case, at least one distortion signal SDANA1, SDANA2. A reduction ~~in particular~~ in the high-frequency spectral components of the detected signals ED1, ED2 indicates incorrect adjustment of the input-side polarization transformer or transformers PMDC, PMDC1, PMDC2, so that it or they can be set  
15 by the further regulator RGW1, RGW2, RGW so as to avoid PMD distortion. This type of method, which is used here only as an auxiliary method, to compensate for polarization mode dispersion is admittedly already known, in principle, for example from European Patent Application EP 0 909 045 A2 and from IEEE J. Lightwave Technology, 17 (1999)9, pages 1602-1616; however, the novel feature  
20 here is its application to polarization-multiplexed signals. As soon as at least one, but preferably both, of the data output signals DD1, DD2 which are obtained from the digital receivers D1, D2 corresponds or corresponds at least approximately to the respective transmission-end modulation signals SDD1, SDD2, the regulator RGW1, RGW2, RGW switches over, so that, according to the present invention,  
25 the input-side control signal LW1, LW2, LW, which is likewise supplied to it and results from detection of interference INT1, INT2, is used to obtain the output-side control signal or signals STW1, STW2.

If a further output-side control signal SDW1, SDW2 changes, the polarization transformation of an input-side polarization transformer PMDC,  
30 PMDC1, PMDC2 is changed. This generally also requires readjustment of one of the output-side polarization transformers SPT, SPT1, SPT2. In order to carry out

this readjustment as quickly as possible, the further regulators RGW1, RGW2 in Figure 10, and the further regulator RGW in Figure 11, each form an information transmission signal ITS1, ITS2, ITS in the further signal processing module DRW. In the signal processing module DRW, this signal is, in each case, supplied to the regulators RG1, RG2 in Figure 3 and to the regulator RG in Figure 5, which regulators use these information transmission signals ITS1, ITS2, ITS to change the output-side control signals STW1, STW2 emitted by them, in order to readjust the output-side polarization transformers SPT, SPT1, SPT2.

The essence of the present invention is always to detect any interference 10 INT1, INT2 which occurs in the two optical signal elements OS1, OS2. The present invention is, therefore, suitable for all operational situations in which such interference INT1, INT2 occurs. This includes the non-return-to-zero signal format, or NRZ for short. It also relates to the return-to-zero signal format, RZ for short, where RZ pulses of the two polarization-multiplexed channels overlap. If 15 these occur alternately, so that there is always one RZ pulse in one channel between two adjacent RZ pulses in the other channel, there is, however, no interference provided the pulse duration is in each case shorter than half the symbol duration. Nevertheless, the present invention ~~can~~ itself can be used usefully in these situations, to be precise for controlling a PMD compensator, which produces the 20 advantageous, interference-free state.

Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the invention as set forth in the hereafter appended claims.

## ABSTRACT OF THE DISCLOSURE

### **Abstract**

Arrangement and method for optical information transmission

A system and method for optical information transmission, wherein

5      ~~In this arrangement and in the associated method,— interference(INT1, INT2), which occurs on the input side for differently polarized optical signal elements(OS1, OS2), between these optical signal elements (OS1, OS2) is detected, a control signal (L1, L2, L12) is formed from it and is used to control a polarization transformer with the downstream fixed polarizing element.~~

10

**Figure 3**

List of reference symbols	
LA	Transmission laser
FM	Optical frequency modulation
5 FMS	Frequency modulation signal
PMC	Transmission end power
splitter	
MO1, MO2	Modulators
SDD1, SDD2	Transmission end modulation
10 signals	
DD1, DD2, DD2-DD1	Data output signals
OS1, OS2	Optical signal elements
PDM1, PDM2, PDM12, PDM21, PFM0, PDML	Phase difference modulating means
15 PHMO1, PHMO2	Angle modulator
PBSS	Transmission end polarization
beam	splitter
PHMO12	Differential angle modulator
DPM	Differential phase modulation
20 FD	Frequency difference
DT1, DT2	Delay times
DT1-DT2	Magnitude of the delay time
difference	
TX1, TX2	Optical transmitters
25 LWL	Optical waveguide
RX	Receiver
EI	Input
SD	Separator/detector
L1, L2, L12, LW1, LW2, LW12, ST1, ST2, STW1, STW2	
30	Control signals
L1, L2, L12, LW1, LW2, LW12	Input side control signals
ST1, ST2, STW1, STW2	Output side control signals
RG1, RG2, RG, RGW1, RGW2, RGW	Regulator
ED1, ED2, ED1-ED2	Detected signals
35 EDV1, EDV2, EDV12, EDW1, EDW2, EDW12	Signals which can be processed
D1, D2	Digital receiver
DR, DRW	Signal processing module
LED1, LED2, LED12, LEDOMn ( $n = 0, 1, 2, \dots$ )	Filter
40 FIO1, FIO2, FIO12, FIOOMn	Spectral signal elements
SUBED12, SUBME, SUBEDW, SUBEDW12, SUBDD21	Subtractor
DET1, DET2, DET12, DETOMn, DETOMmn ( $m, n = 0, 1, 2, \dots$ )	Detector
45 LPF1, LPF2, LPF12	Low pass filter
PD11, PD21	Photodetectors
EPBS, EPBS1, EPBS2	Fixed polarizing elements

	PT, PT1, PT2	Controllable polarization
	transformers	
	PMDC, PMDC1, PMDC2	Input side polarization
	transformers,	PMD
5	compensators	
	SPT, SPT1, SPT2	Output side polarization
	transformers	
	SUB, SUB1, SUB2	Controllable polarizing
	elements	
10	OUT1, OUT2	Signal components
	TE	Receiver end power splitter
	x, y	Coordinates for
	horizontal/vertical	polarization
	FE1, FE2, FE12, FEW1, FEW2, FEW12	Filter unit
15	OM	Modulation frequency
	n*OM (n = 0, 1, 2, ...)	Multiples of the modulation
	frequency	
	LOMn	Power transmission factors
	Gn	Weights
20	SOMn, SOMmn	Second order moments
	F	Function
	ADD	Adder
	SE	Subtractor unit
	PEVEN	First power
25	PODD	Second power
	PEVEN+PODD	Sum of PEVEN and Podd
	ME1, ME2, ME12	Correlating elements
	EIME11, EIME21, EIME1, EIME12, EIME22, EIME2	
		Correlation inputs
30	SEW	Correlating subtraction unit
	SEE	Switching element
	EISE1, EISE2	Switching element inputs
	DEL, DDEL	Delay elements
	CL	Clock signal
35	DFF	D-Flipflop
	DF1, DF2	Differential amplifiers
	TT1, TT2	Switching transistors
	I1, I2	Currents
	R1, R2	Resistors
40	C	Capacitor
	U+	Supply voltage
	DANA1, DANA2	Distortion analyzers
	SDANA1, SDANA2	Distortion signals

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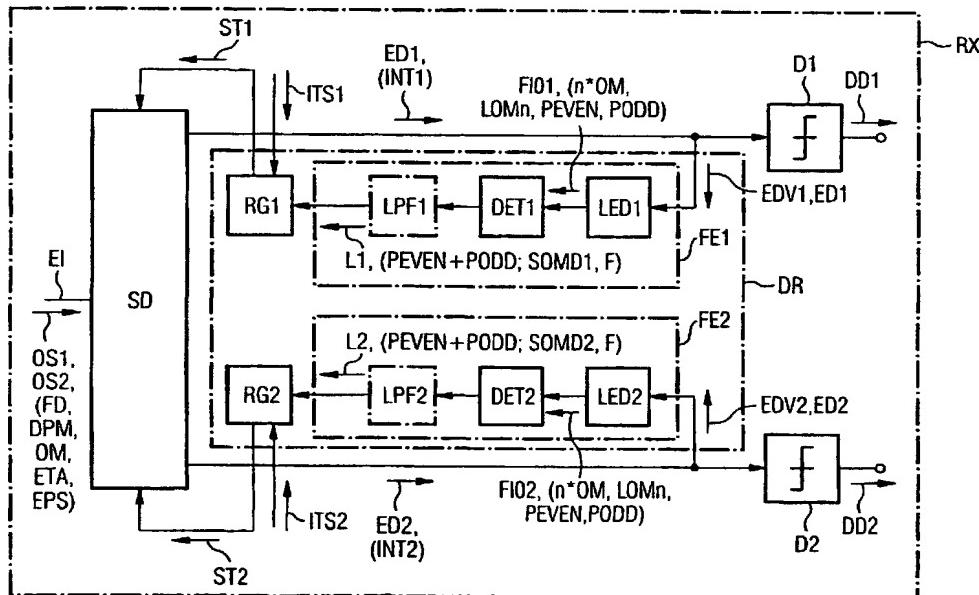
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[Fortsetzung auf der nächsten Seite]

(54) Title: DEVICE AND METHOD FOR OPTICAL TRANSMISSION OF INFORMATION

(54) Bezeichnung: ANORDNUNG UND VERFAHREN FÜR EINE OPTISCHE INFORMATIONSÜBERTRAGUNG

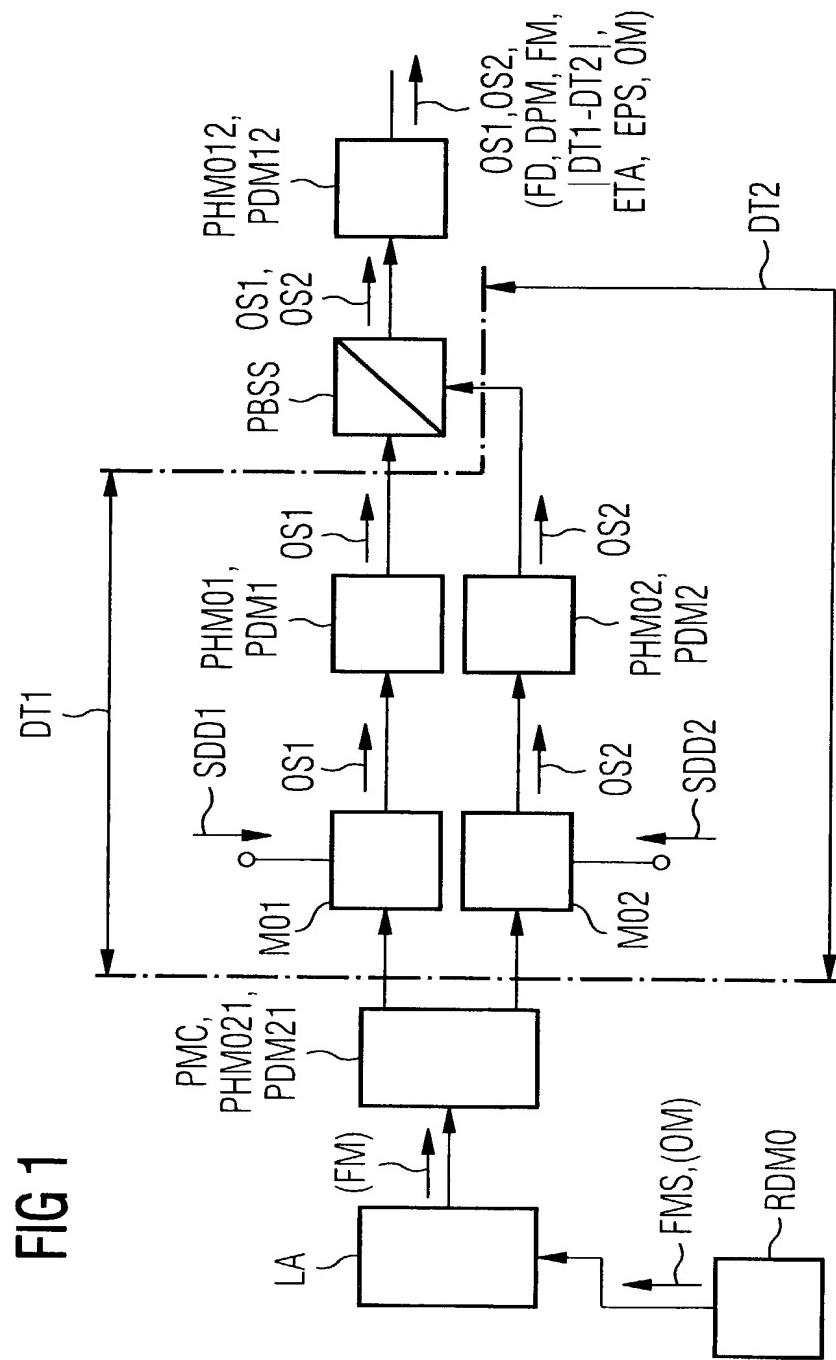


(57) Abstract: A device and method, wherein interference (INT1, INT2) occurring in the receiver for various polarized optical partial signals (OS1, OS2) is detected therebetween; a control signal (L1, L2, L12) is formed and used to control a polarization transformer with a fixed downstream polarizing element.

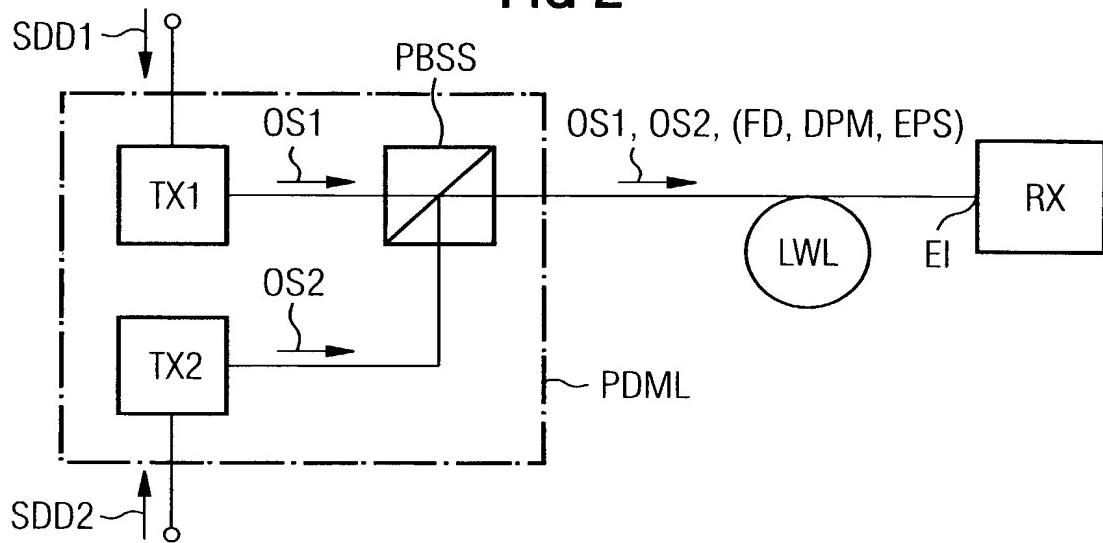
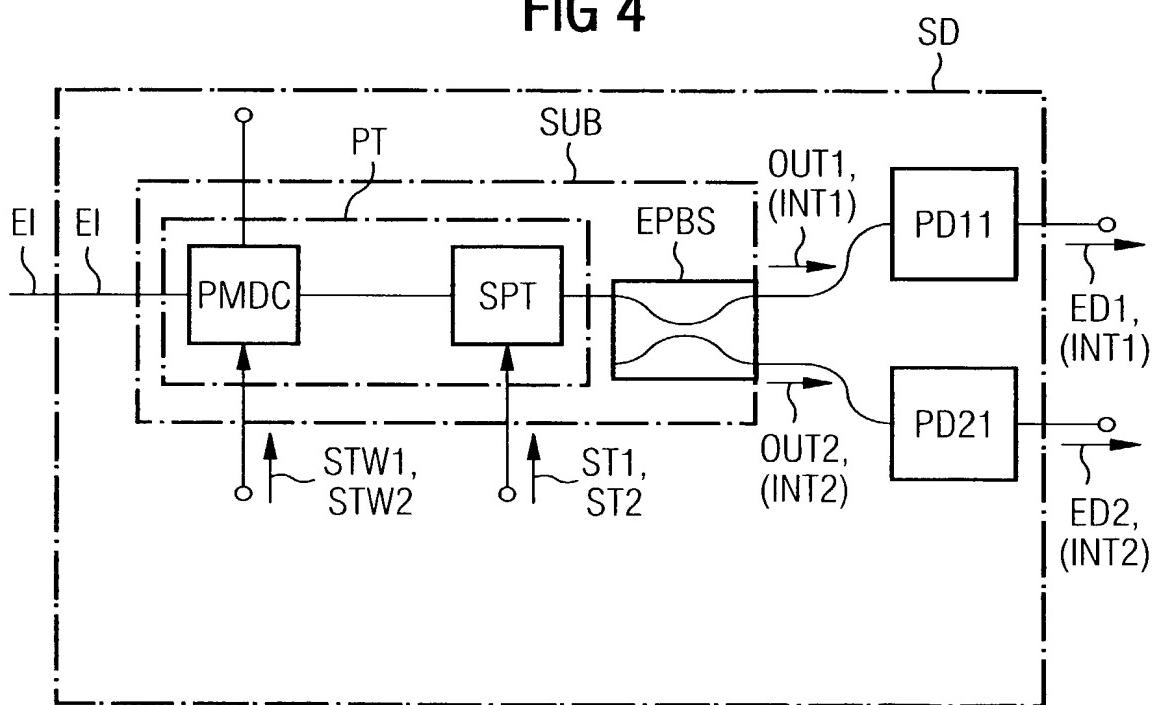
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**FIG 2****FIG 4**

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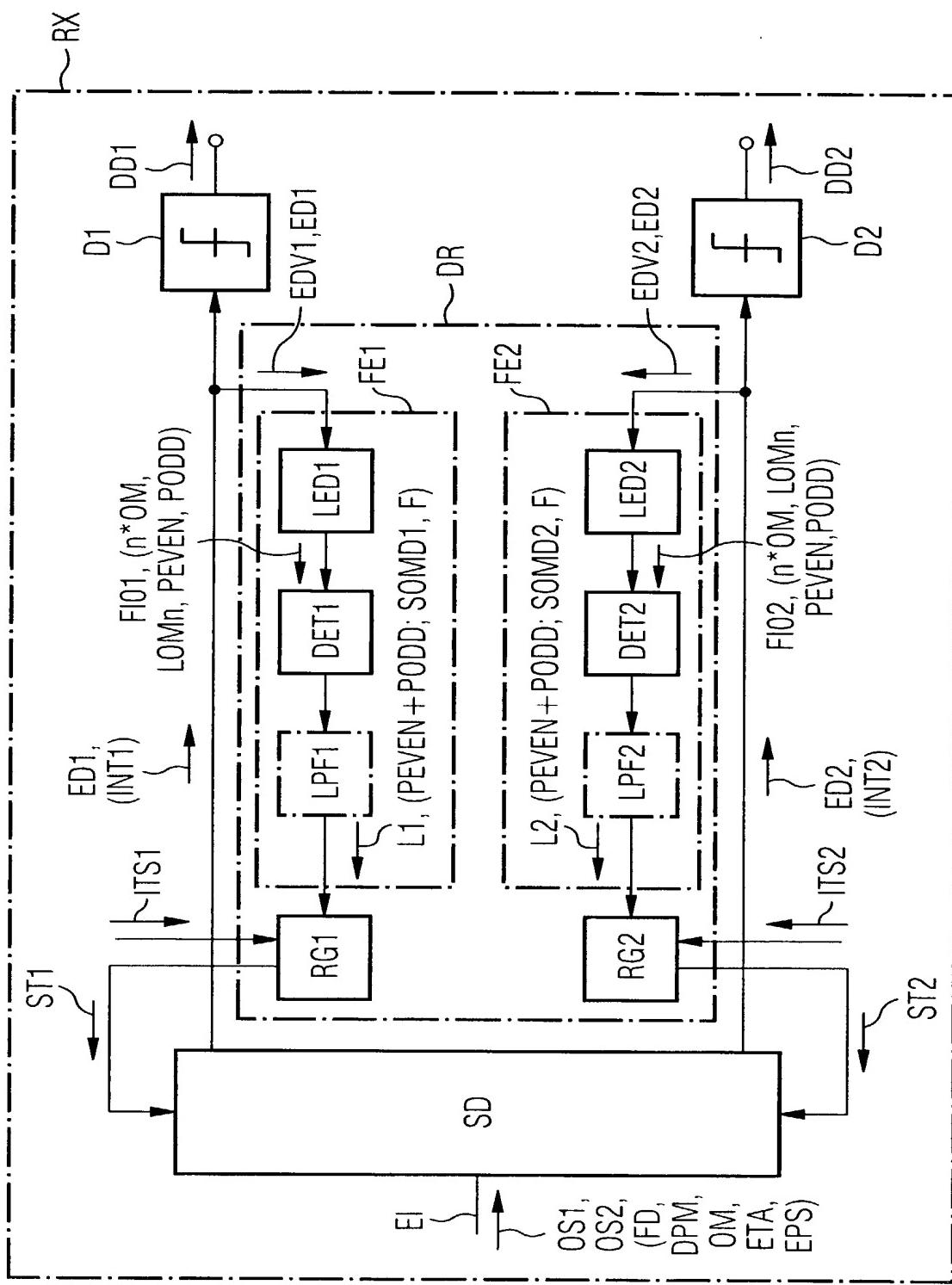
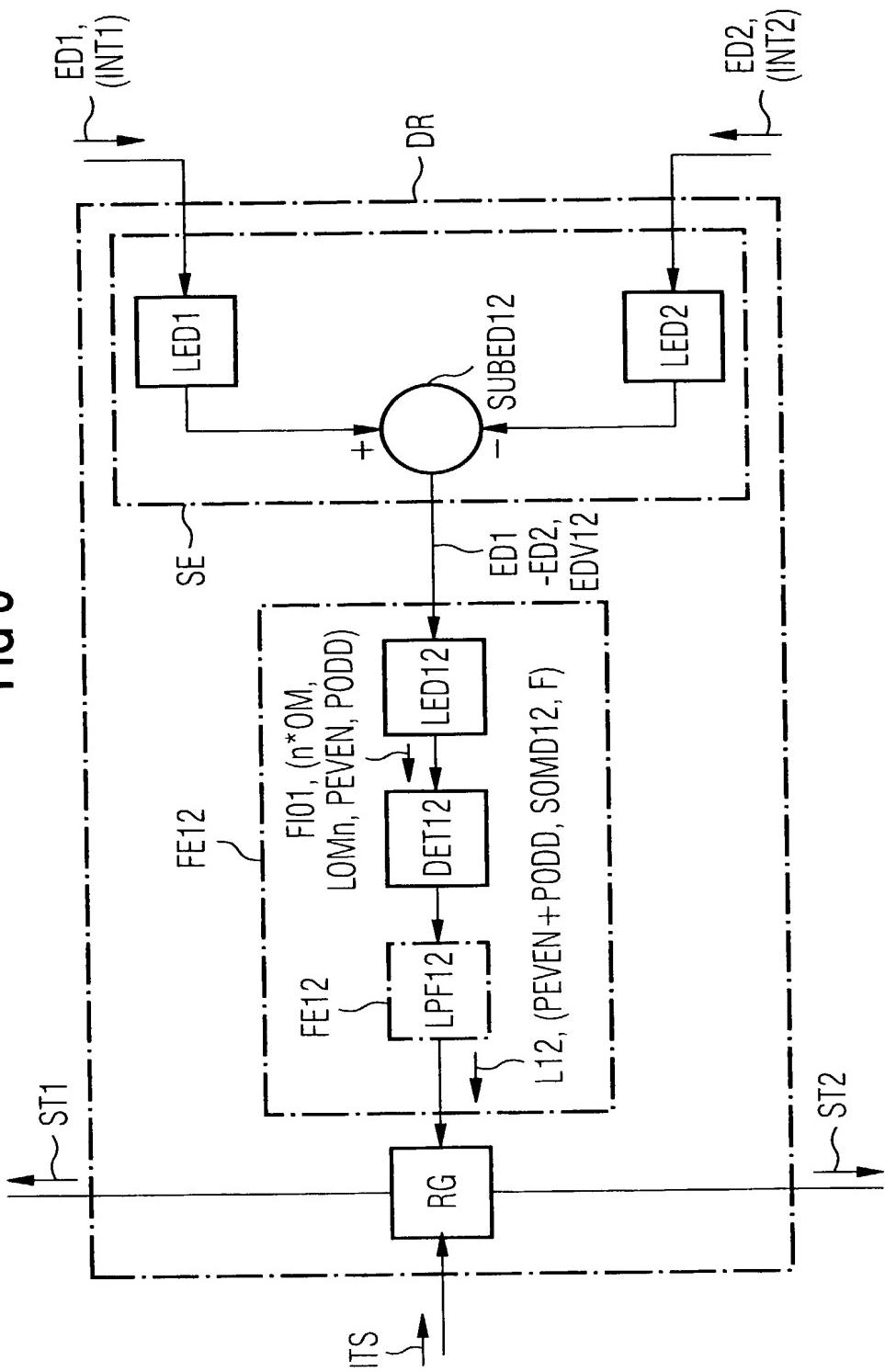


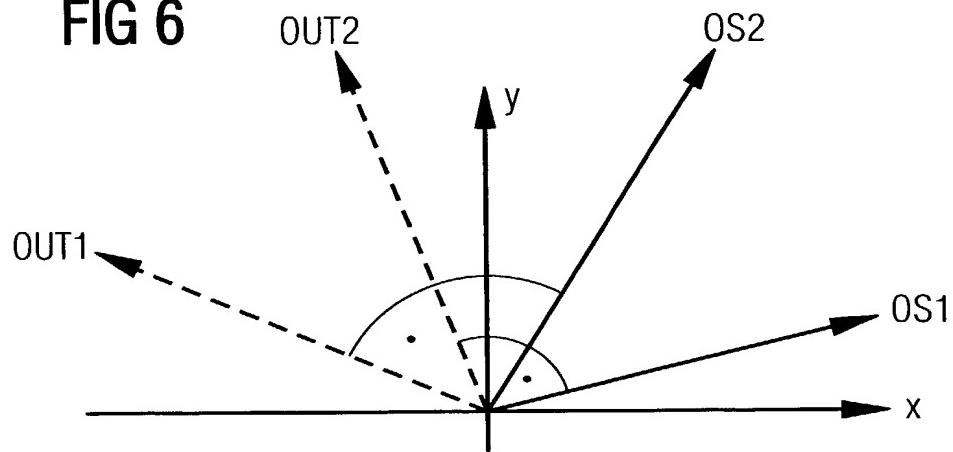
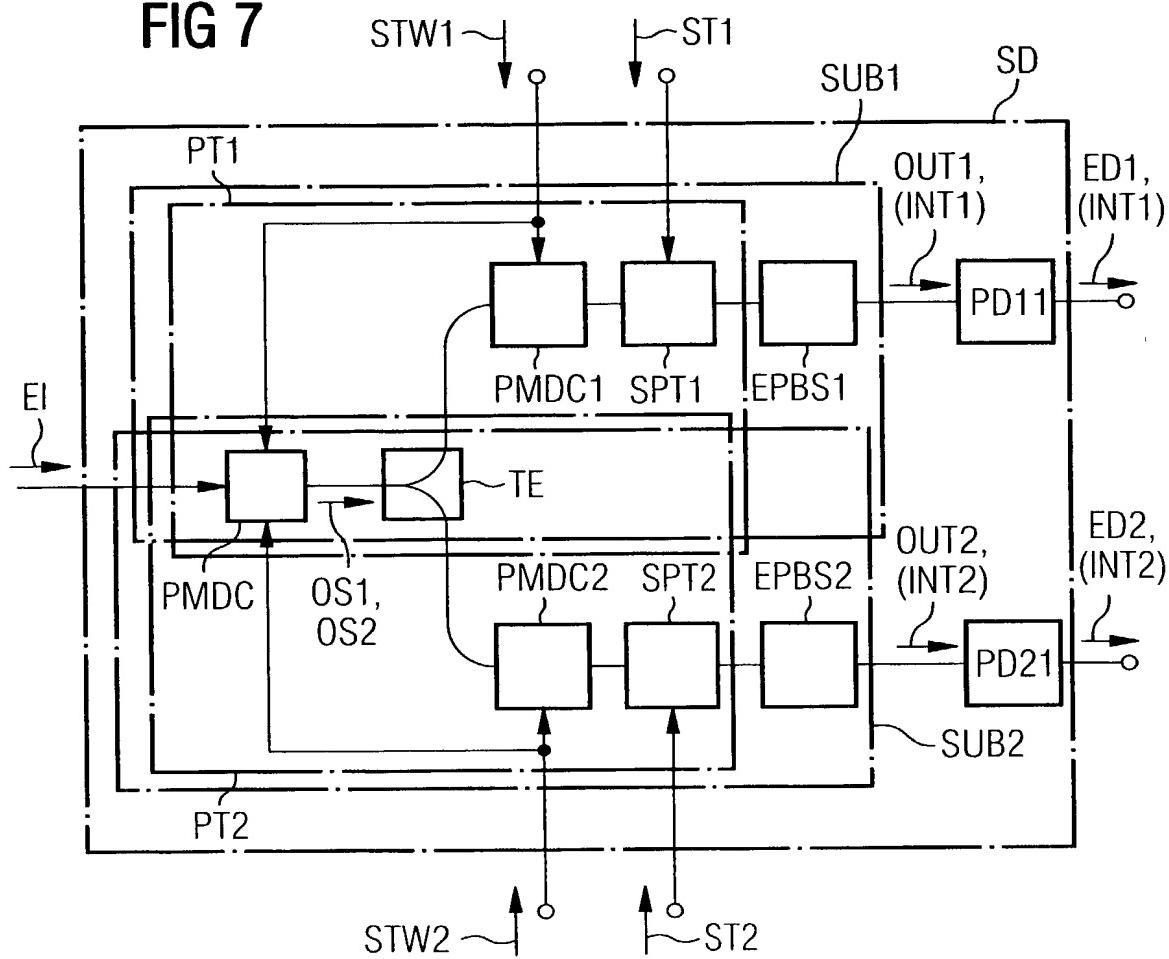
FIG 3

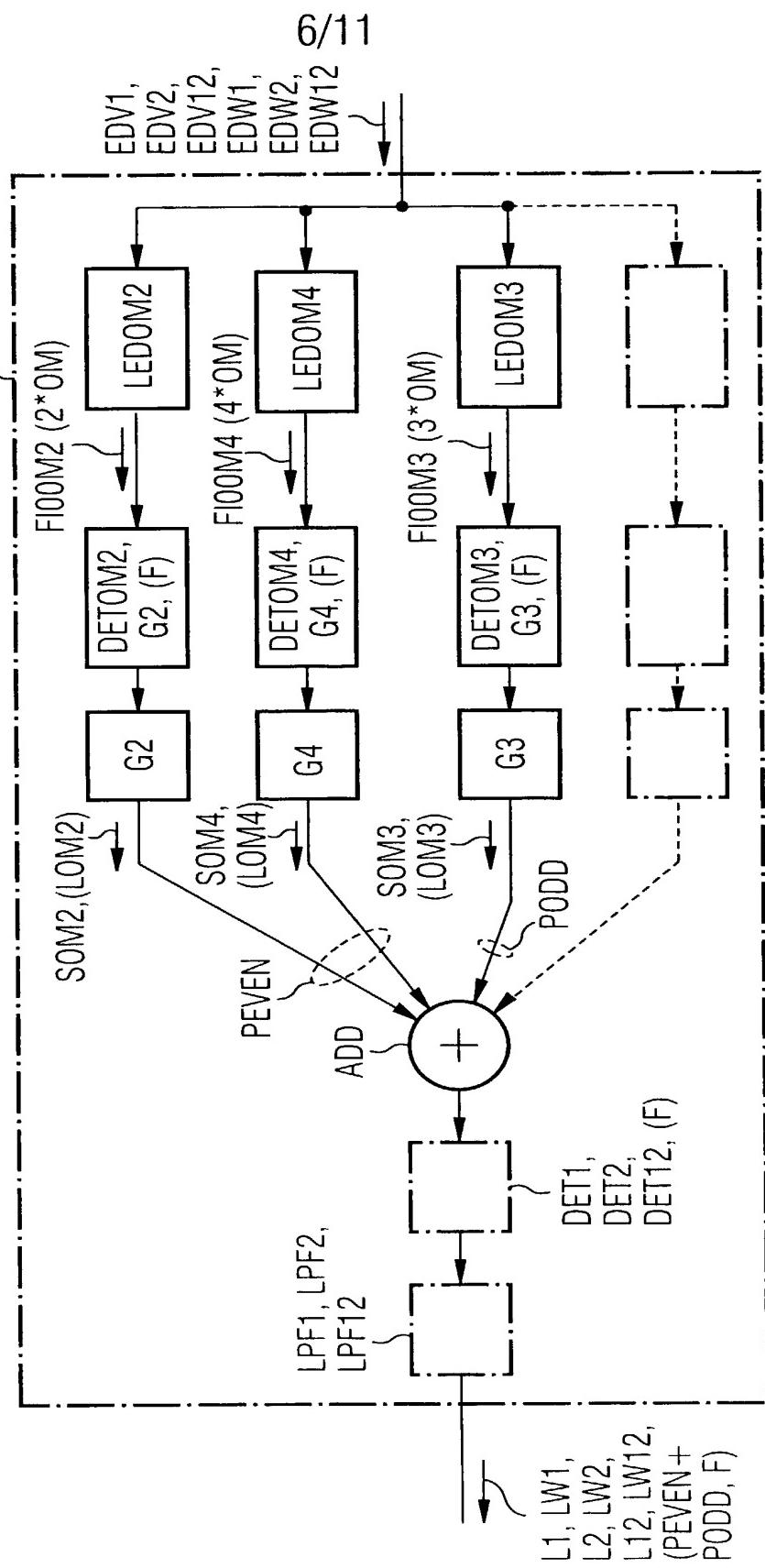
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FIG 5



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**FIG 6****FIG 7**

**FIG 8**

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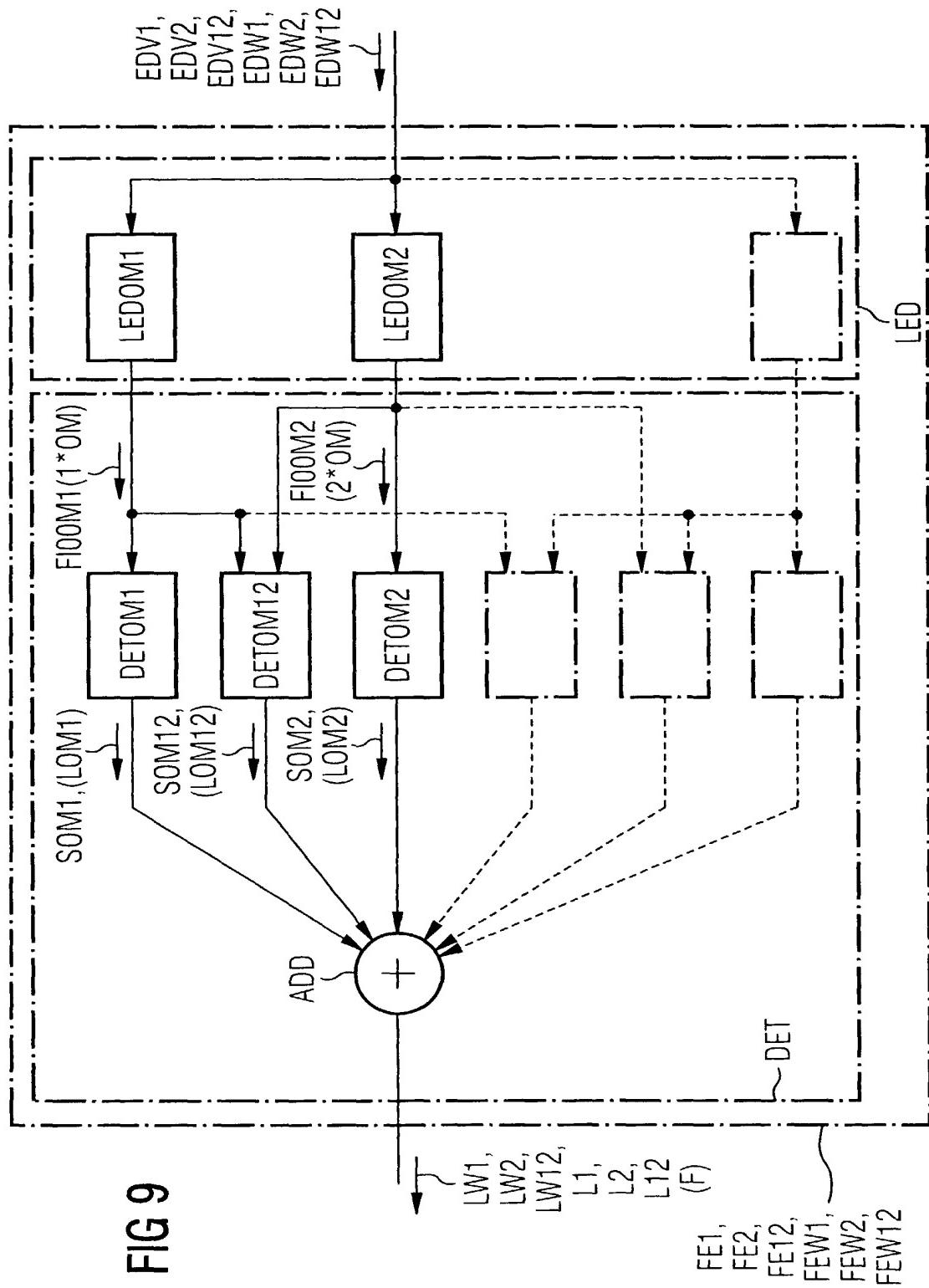
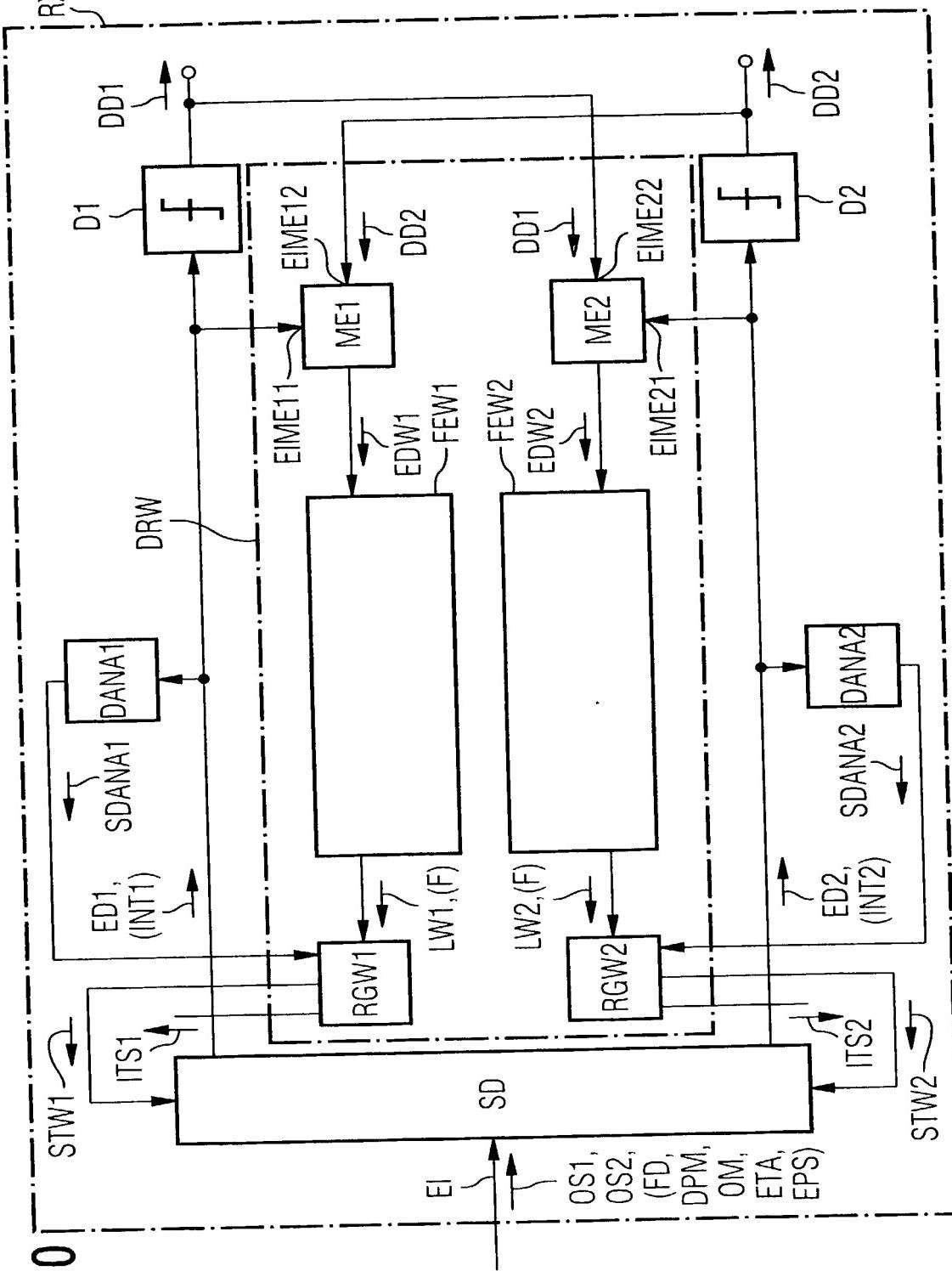


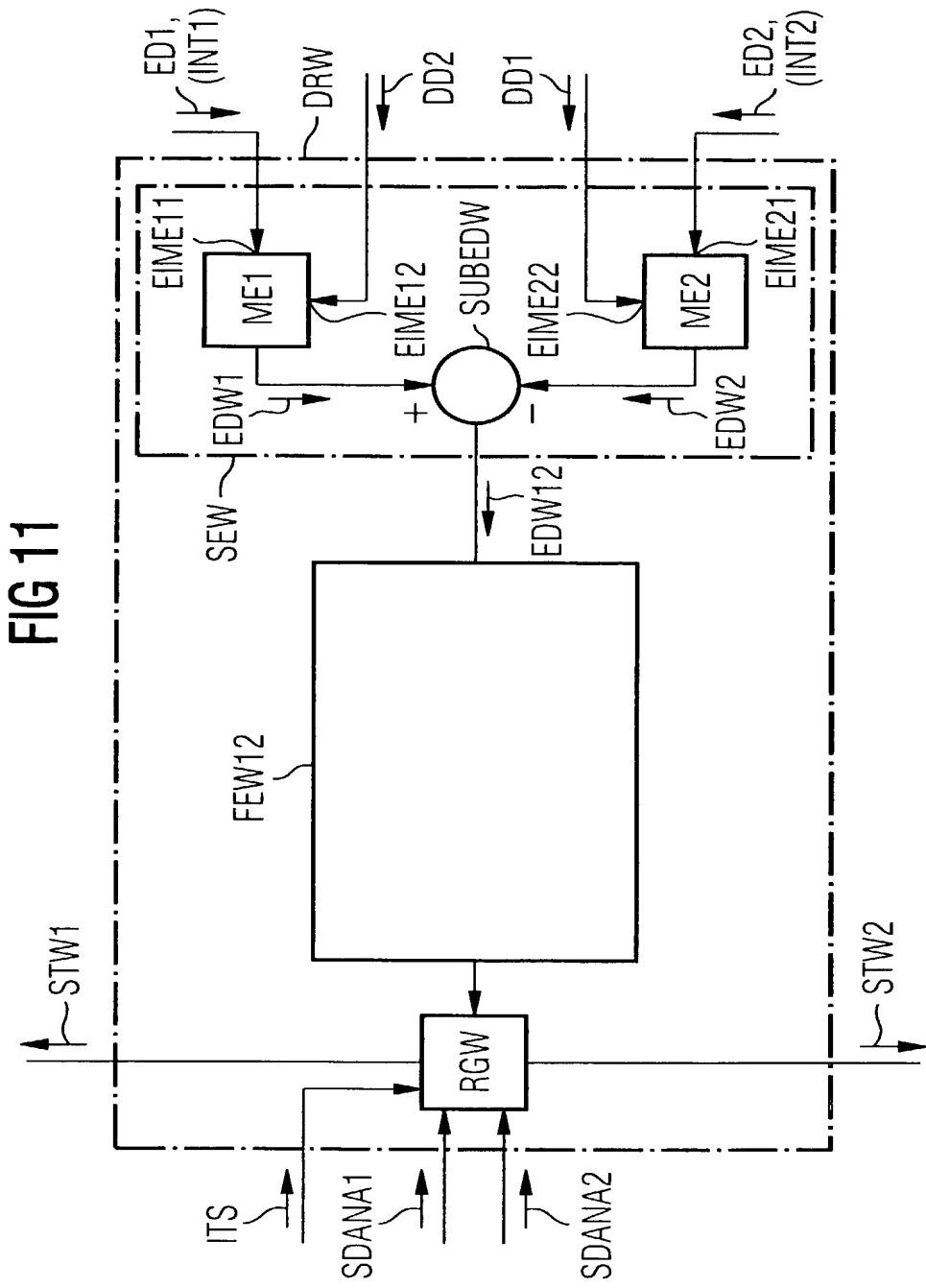
FIG 9

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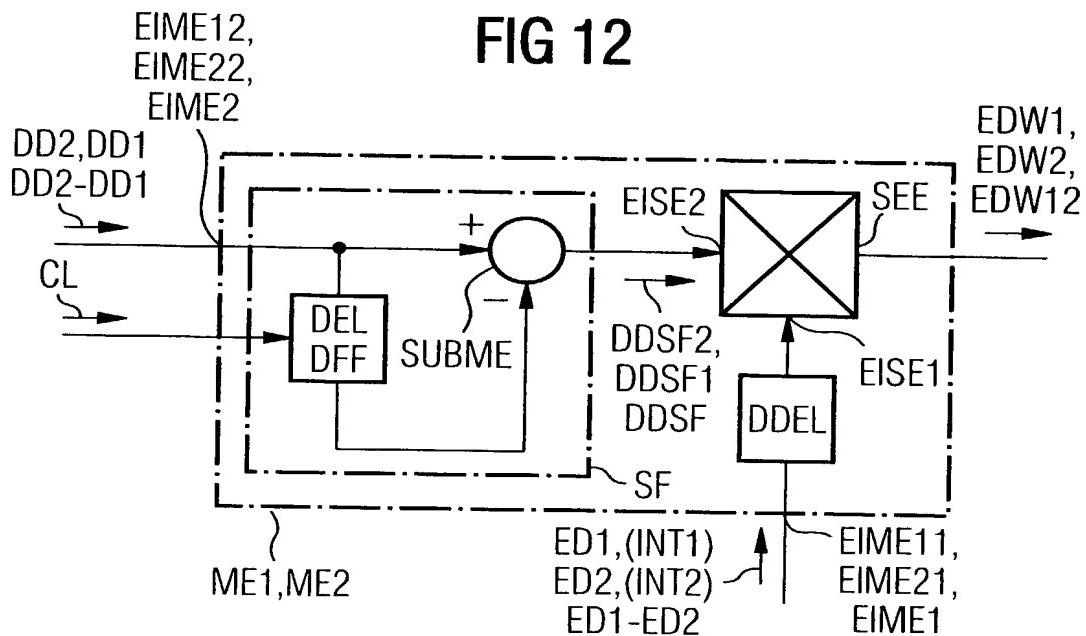
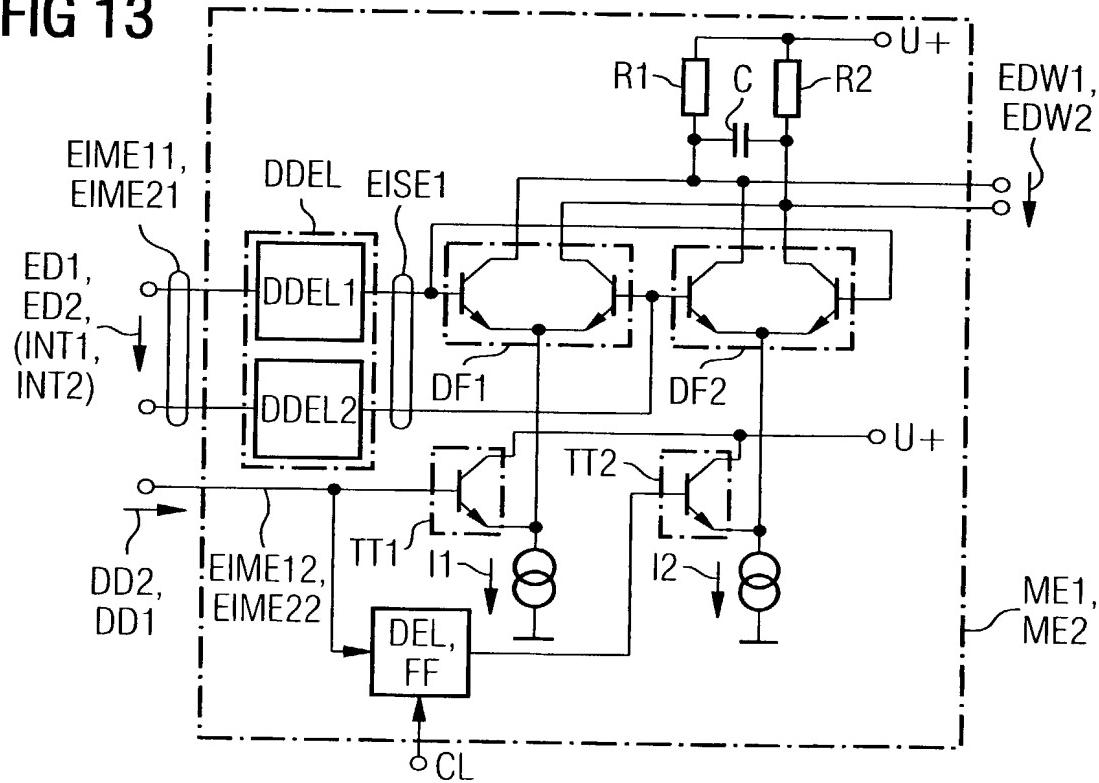
RX



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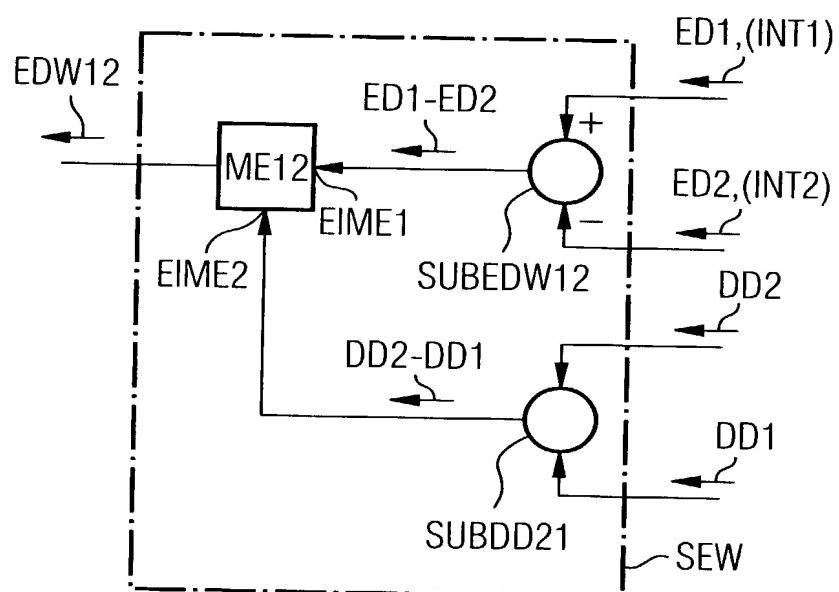


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**FIG 12****FIG 13**

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FIG 14



**Declaration and Power of Attorney For Patent Application**  
**Erklärung Für Patentanmeldungen Mit Vollmacht**  
**German Language Declaration**

10/07/03  
 24.08.2002

Als nachstehend benannter Erfinder erkläre ich hiermit an Eides Statt:

dass mein Wohnsitz, meine Postanschrift, und meine Staatsangehörigkeit den im Nachstehenden nach meinem Namen aufgeführten Angaben entsprechen,

dass ich, nach bestem Wissen der ursprüngliche, erste und alleinige Erfinder (falls nachstehend nur ein Name angegeben ist) oder ein ursprünglicher, erster und Miterfinder (falls nachstehend mehrere Namen aufgeführt sind) des Gegenstandes bin, für den dieser Antrag gestellt wird und für den ein Patent beantragt wird für die Erfindung mit dem Titel:

**Anordnung und Verfahren für eine optische Informationsübertragung**

deren Beschreibung

(zutreffendes ankreuzen)

hier beigelegt ist.

am 05.09.2000 als

PCT internationale Anmeldung

PCT Anmeldungsnummer PCT/DE00/03066

eingereicht wurde und am \_\_\_\_\_

abgeändert wurde (falls tatsächlich abgeändert).

Ich bestätige hiermit, dass ich den Inhalt der obigen Patentanmeldung einschließlich der Ansprüche durchgesehen und verstanden habe, die eventuell durch einen Zusatzantrag wie oben erwähnt abgeändert wurde.

Ich erkenne meine Pflicht zur Offenbarung irgendwelcher Informationen, die für die Prüfung der vorliegenden Anmeldung in Einklang mit Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) von Wichtigkeit sind, an.

Ich beanspruche hiermit ausländische Prioritätsvorteile gemäß Abschnitt 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 119 aller unten angegebenen Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde, und habe auch alle Auslandsanmeldungen für ein Patent oder eine Erfindersurkunde nachstehend gekennzeichnet, die ein Anmelde datum haben, das vor dem Anmelde datum der Anmeldung liegt, für die Priorität beansprucht wird.

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

**Device and method for optical transmission of information**

the specification of which

(check one)

is attached hereto.

was filed on 05.09.2000 as

PCT international application

PCT Application No. PCT/DE00/03066

and was amended on \_\_\_\_\_

(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, §1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

**German Language Declaration**

Prior foreign applications  
Priorität beansprucht

Priority Claimed

<u>19942936.7</u> (Number)	<u>DE</u> (Country)	<u>08.09.1999</u> (Day Month Year Filed) (Tag Monat Jahr eingereicht)	<input checked="" type="checkbox"/> Yes Ja	<input type="checkbox"/> No Nein
<u>10017516.3</u> (Number)	<u>DE</u> (Country)	<u>10.04.2000</u> (Day Month Year Filed) (Tag Monat Jahr eingereicht)	<input checked="" type="checkbox"/> Yes Ja	<input type="checkbox"/> No Nein
<u>10019932.1</u> (Number)	<u>DE</u> (Country)	<u>20.04.2000</u> (Day Month Year Filed) (Tag Monat Jahr eingereicht)	<input checked="" type="checkbox"/> Yes Ja	<input type="checkbox"/> No Nein

Ich beanspruche hiermit gemäss Absatz 35 der Zivilprozessordnung der Vereinigten Staaten, Paragraph 120, den Vorzug aller unten aufgeführten Anmeldungen und falls der Gegenstand aus jedem Anspruch dieser Anmeldung nicht in einer früheren amerikanischen Patentanmeldung laut dem ersten Paragraphen des Absatzes 35 der Zivilprozeßordnung der Vereinigten Staaten, Paragraph 122 offenbart ist, erkenne ich gemäss Absatz 37, Bundesgesetzbuch, Paragraph 1.56(a) meine Pflicht zur Offenbarung von Informationen an, die zwischen dem Anmelde datum der früheren Anmeldung und dem nationalen oder PCT internationalen Anmelde datum dieser Anmeldung bekannt geworden sind.

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §122, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

<u>PCT/DE00/03066</u> (Application Serial No.) (Anmeldeseriennummer)	<u>05.09.2000</u> (Filing Date D, M, Y) (Anmelde datum T, M; J)	<u>anhängig</u> (Status) (patentiert, anhängig, aufgegeben)	<u>pending</u> (Status) (patented, pending, abandoned)
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<u>(Application Serial No.)</u> <u>(Anmeldeseriennummer)</u>	<u>(Filing Date D,M,Y)</u> <u>(Anmelde datum T, M; J)</u>	<u>(Status)</u> (patentiert, anhängig, aufgegeben)	<u>(Status)</u> (patented, pending, abandoned)
-----------------------------------------------------------------	--------------------------------------------------------------	----------------------------------------------------------	------------------------------------------------------

Ich erkläre hiermit, dass alle von mir in der vorliegenden Erklärung gemachten Angaben nach meinem besten Wissen und Gewissen der vollen Wahrheit entsprechen, und dass ich diese eidestattliche Erklärung in Kenntnis dessen abgebe, dass wissentlich und vorsätzlich falsche Angaben gemäss Paragraph 1001, Absatz 18 der Zivilprozessordnung der Vereinigten Staaten von Amerika mit Geldstrafe belegt und/oder Gefängnis bestraft werden können, und dass derartig wissentlich und vorsätzlich falsche Angaben die Gültigkeit der vorliegenden Patentanmeldung oder eines darauf erteilten Patentes gefährden können.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

## German Language Declaration

**VERTRETUNGSVOLLMACHT:** Als benannter Erfinder beauftrage ich hiermit den nachstehend benannten Patentanwalt (oder die nachstehend benannten Patentanwälte) und/oder Patent-Agenten mit der Verfolgung der vorliegenden Patentanmeldung sowie mit der Abwicklung aller damit verbundenen Geschäfte vor dem Patent- und Warenzeichenamt: (*Name und Registrationsnummer anführen*)

**POWER OF ATTORNEY:** As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith. (*list name and registration number*)



29177 And I hereby appoint

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 or  
**Customer No. 29177**

Voller Name des einzigen oder ursprünglichen Erfinders: <b>Prof. REINHOLD NOE</b>	Full name of sole or first inventor: <b>Prof. REINHOLD NOE</b>		
Unterschrift des Erfinders <i>Reinhold Noe</i>	Datum 20.01.02	Inventor's signature	Date
Wohnsitz <b>PADERBORN, DEUTSCHLAND</b>	Residence <b>PADERBORN, GERMANY</b>		
Staatsangehörigkeit <b>AT</b>	Citizenship <b>AT</b>		
Postanschrift <b>HELMERNER WEG 2</b>	Post Office Address <b>HELMERNER WEG 2</b>		
<b>33100 PADERBORN</b>	<b>33100 PADERBORN</b>		
Voller Name des zweiten Miterfinders (falls zutreffend):	Full name of second joint inventor, if any:		
Unterschrift des Erfinders	Datum	Second inventor's signature	Date
Wohnsitz	Residence		
Staatsangehörigkeit	Citizenship		
Postanschrift	Post Office Address		

(Bitte entsprechende Informationen und Unterschriften im Falle von dritten und weiteren Miterfindern angeben).

(Supply similar information and signature for third and subsequent joint inventors).